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Movements and Distributions of Radio-Tagged Northern Pike in Harding Lake

by

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ABSTRACT

Radio-transmitters were surgically implanted in 14 male and 12 female northern pike *Esox lucius* to estimate movements and distributions relative to vegetation type and depth of water column in Harding Lake, Alaska. Straight line distances moved were determined for 1-day, 3-day, and 7-day intervals from 8 June to 2 July, 1992. Half of the radio-tagged northern pike moved at least a mean distance of 0.29 kilometers between 1-day intervals, 0.33 kilometers between 3-day intervals, and 0.47 kilometers between 7-day intervals. Distribution in relation to vegetation and water depth were determined from 8 June to 30 September, 1992. The proportion of radio-tagged northern pike found in vegetation increased from 8 June to 2 July and then decreased from 6 July to 30 September. From 8 June to 2 July, males were found more often than females in vegetation, large males more often than small males, and small females more often than large females. Distributions relative to vegetation and water depth by sex and size were most similar in late June. From 8 June to 2 July all radio-tagged northern pike remained in water depth less than 3 meters. Large males moved into deeper water in July, followed by small males in August, and females in September. These findings indicate that northern pike mark-recapture experiments, using current methods of backpack electrofishing and variable-mesh gill nets, should be delayed until Harding Lake is completely ice-free and should be completed before July. In addition, this study suggests that catch-per-unit of effort will increase and sampling bias, due to different distributions by size and sex, will decrease as June progresses. To insure adequate mixing of northern pike between mark-recapture events in Harding Lake, the width of sampling sections would need to be 0.29 kilometers for a 1-day hiatus, 0.33 kilometers for a 3-day hiatus, and 0.47 kilometers for a 7-day hiatus.

KEY WORDS: Northern pike, *Esox lucius*, Harding Lake, radio-telemetry, mark-recapture experiments, fish distribution, movements.

INTRODUCTION

Since 1990 the Alaska Department of Fish and Game (ADF&G) has annually conducted two-event mark-recapture experiments to estimate the abundance, recruitment, age composition, and length composition of the northern pike *Esox lucius* population 300 mm fork length (FL) and larger in Harding Lake. Historic rates of recapture by length suggest that population compositions were different during the first and second events. In 1990, the abundance estimate included only northern pike greater than 450 mm because smaller fish were not recaptured in the second event (Burkholder 1990). For 1991 and 1992 the estimates of abundance were stratified by size because the size composition of the sample changed from the first event to the second event (Skaugstad and Burkholder 1992). Small fish that were marked in the first events of the mark-recapture experiments were not represented at the expected frequency in the second events (Figure 1).

Sampling strategies for northern pike in Harding Lake should consider the movements and distributions of these fish. Northern pike prefer the littoral zone of lakes and have been closely linked to the vegetation of these lakes. Diana et al. (1977) reported that northern pike in Lac Ste. Anne, Alberta preferred habitat within 300 m of shore, areas of vegetation, and water depths less than 4 m. Chapman and Mackay (1984a and 1984b) also suggested that northern pike, in the deeper of Twin Lakes, and in Seibert Lake, Alberta, predominantly utilized the shallow vegetated areas. Pearse and Clark (1992) found that both male and female northern pike in Volkmar Lake, Alaska, preferred vegetated habitat from mid-May to early August.

Northern pike generally concentrate for spawning in densely vegetated areas and in water depth less than 1 m (Wright and Shoesmith 1988). In interior Alaska lakes, northern pike move into spawning areas as soon as shallow vegetated areas are ice-free, usually mid-May to early June. Sampling northern pike in interior Alaska lakes has been timed to take advantage of the high densities of northern pike in shallow water during and after spawning. Peckham and Bernard (1987) recommended that in-shore sampling of northern pike be completed before the middle of June for Volkmar, T, and George lakes because catch-per-unit of effort (CPUE) drops off dramatically after this time. It has been suggested that CPUE is higher before mid-June because the northern pike concentrate in spawning areas during this time and CPUE decreases after mid-June because the fish distribute to deeper (> 3 m) vegetated waters and become more sedentary (Pearse and Clark 1992).

Field work designed to estimate the abundance and composition of northern pike in Harding Lake has been scheduled in late May and early June during breakup because it was assumed that northern pike in Harding Lake behave similar to northern pike in Volkmar, T, and George lakes (Burkholder 1990; and Skaugstad and Burkholder 1992) and would be more difficult to capture later in June. However, the average number of fish captured per day using similar gear at similar depths increased substantially from the first events to the second events during the Harding Lake mark-recapture experiments of 1990, 1991, and 1992 (Table 1). The window of opportunity for acceptable or improved CPUE in Harding Lake may be wider than previously thought and may extend through June because of habitat differences found in Harding Lake.

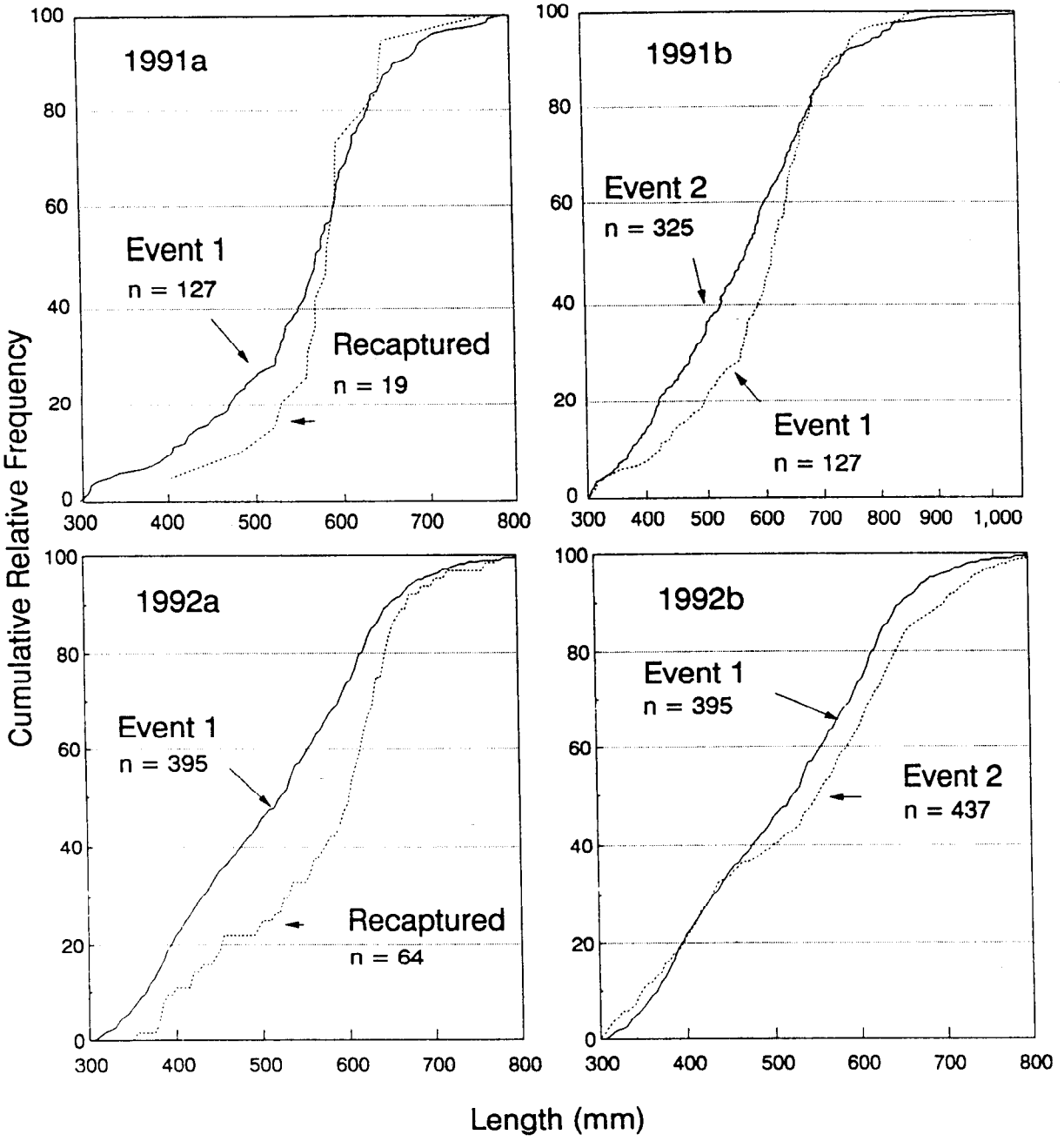

Figure 1. Cumulative relative frequencies of northern pike, (a) marked in event one and recaptured in event two, and (b) all northern pike captured in event one and event two for mark recapture experiments in Harding Lake in 1991 and 1992 (data from Skaugstad and Burkholder 1992).

Table 1. Mean number of northern pike captured per day from Harding Lake during the first and second event of mark-recapture experiments during 1990, 1991, and 1992[a].

	Event				
	1st	(s.d)	2nd	(s.d.)	*P*
1990[b]	41.3	(19.2)	107.5	(13.4)	0.0008
1991[c]	35.2	(24.7)	81.8	(14.9)	0.0035
1992[d]	49.3	(35.3)	123.0	(35.3)	0.0006

[a] Burkholder 1990, Skaugstad and Burkholder 1992.
[b] Dates of the first event were 14 through 25 May, and of the second event 29 through 31 May 1990.
[c] Dates of the first event were 28 through 31 May, and of the second event 3 through 7 June 1991.
[d] Dates of the first event were 26 through 29 May, 3 through 5 June, and 8 through 9 June, and of the second event 15 through 18 June 1992.

The goal of this study was to more fully understand the movements and distributions of northern pike in Harding Lake so that a more efficient and effective method of assessing the abundance and composition of the northern pike population in Harding Lake can be developed. The objectives were to:

1) estimate the minimum average daily movement of northern pike in Harding Lake; and,

2) estimate the proportion of northern pike > 450 mm FL in Harding Lake that are located from shore to 3 m in water depth on a daily basis during June 1992.

In addition, the movements and distributions of northern pike in Harding Lake from June through September 1992 were described in relation to water depth and vegetation by length and sex.

Study Site

This study was conducted in Harding Lake, the largest road accessible lake in the Tanana River drainage. It has a surface area of 1,000 ha, a maximum depth of 43 m, a surface elevation of 217 m, and is located 69 km southeast of Fairbanks off the Richardson Highway. Harding Lake is circular in shape with a prominent point along the southern shore and a small point along the northern shore. There are two inlets; the East Inlet enters the northeast corner of the lake, and the Little Harding Lake Inlet enters the southwest corner. There are no outlets from Harding Lake (Figure 2).

Harding Lake was described as oligotrophic by LaPerriere (1975) and Nakao (1980). Most of Harding Lake is in an open-water zone with almost all of the marginal vegetation (emergent grasses) found along the north and northeast shores in water < 1 m deep. However, more than half of the shallow water (< 3 m depth) in the north and northeast area of the lake is free of vegetation. There are some deep weed beds of *Potamageton* sp. and *Chara* sp. located sporadically at about the 5 m contour. The littoral zone (the area from zero depth to the outer margin of the deep weed-beds) comprises less than 33% of the surface area of the lake. However, there are large areas within this zone that are free of vegetation. The emergent vegetation comprises less than 10% of the surface area of the lake.

METHODS

Radio-telemetry was used to track the movements and determine distributions of 26 northern pike in Harding Lake. Telemetry is an effective method for determining location of fish. Several investigators have successfully used telemetry to monitor distribution relative to habitat characteristics and track northern pike movements (Poddubnyi et al. 1970; Diana et al. 1977, Diana 1980; Ross and Winter 1981; Chapman and Mackay 1984a, 1984b; Cook and Bergersen 1988; Holmes and Burkholder 1988; Pearse and Clark 1992). Radio-telemetry increases the ability to locate and follow a specific fish over

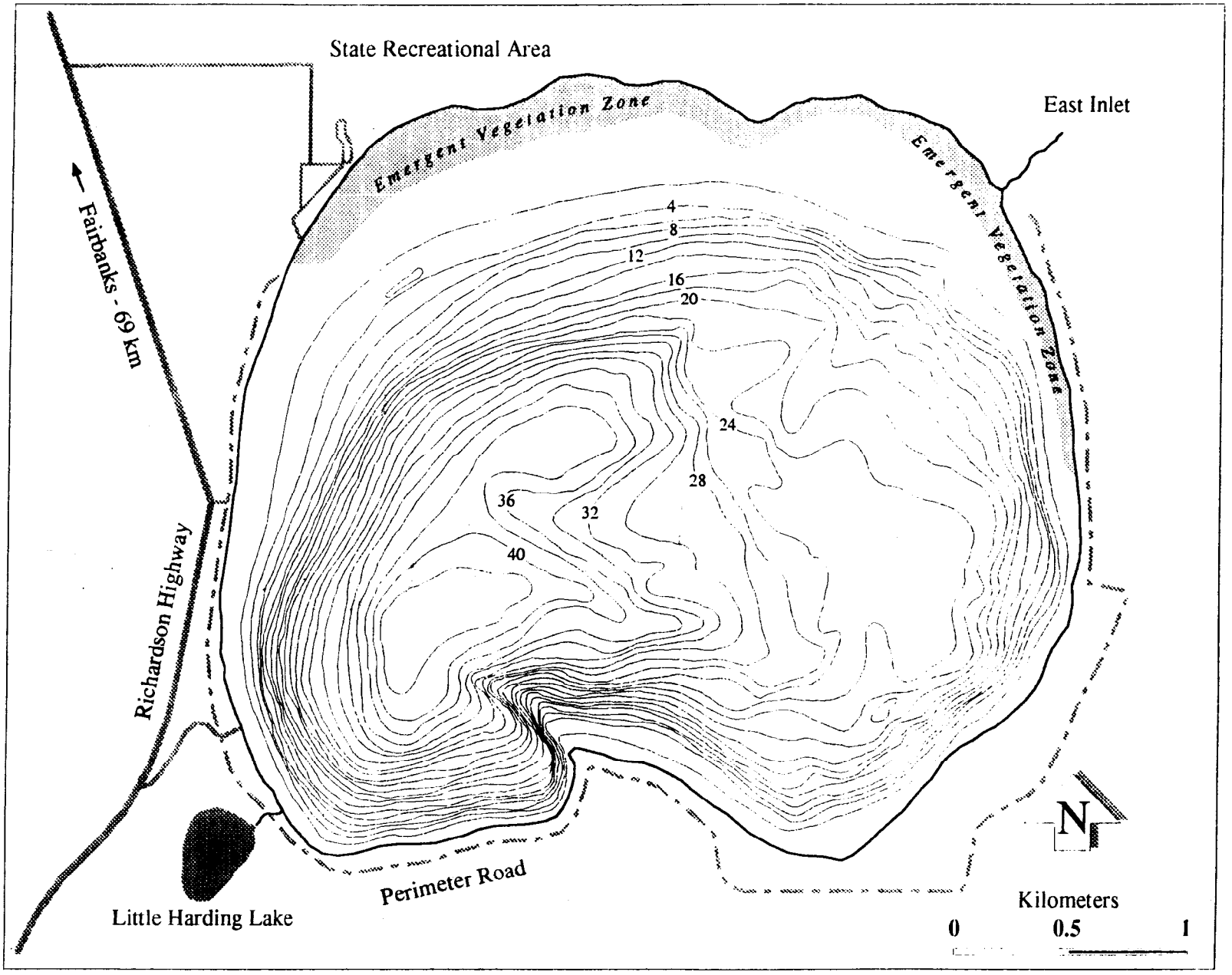

Figure 2. Map of Harding Lake showing depth contours (m), emergent vegetation, and other characteristics.

time, compared to visual observation or relying on the recapture of the same fish for data.

Radio-Transmitters and Tagging Methodology

The radio-transmitters used in this study were manufactured by Telonics Inc.[1] (model CHP-4P). The length of the radio-transmitters (excluding antenna) were 4.8 cm, the diameter 1.5 cm, the weight ranged from 14.05 g to 15.60 g, and the length of the antenna 45 cm. Each radio-transmitter had a unique frequency between 148.200 and 148.630 MHz and an expected life of 16 to 32 months, at 75 to 35 pulses per minute.

Between 26 May and 29 May 1992, 26 radio-transmitters were surgically implanted in 14 male (eight larger than 580 mm fork length (FL) and six smaller than 580 mm) and 12 female (five larger than 580 mm and seven smaller than 580 mm) northern pike captured from Harding Lake with variable mesh gill nets and back-pack electrofishing gear. All fish captured were collected from vegetation along the northern and eastern shore; all females were collected from the eastern shore. Sex was easily determined for these fish because of the presence of sex products. The radio-transmitters were placed in the coelomic cavity through a 2 cm incision along the linea alba, anterior to the pelvic girdle (Hart and Summerfelt 1975). Three to five sutures were necessary to close the incision. The outlet incision for the trailing antenna was posterior to the pelvic girdle. This procedure was similar to the method described by Ross (1982), with the exception that a blunt needle was used to guide the antenna to the outlet incision instead of a shielded needle. Radio-tagged fish were immediately released after regaining equilibrium.

Locating Radio-Tagged Fish

Tracking each fish was attempted daily from 8 June through 2 July 1992 (except 21 and 28 June), weekly from 6 July through 27 July, once in August (7 August), and twice in September (8 and 30 September). For each tracking event, all frequencies were programmed into a TS-1 scanner-programmer that was attached to a TR-2 receiver (both manufactured by Telonics, Inc.[1]). Locating fish consisted of motoring around the perimeter of the lake while listening for a signal with an eight-element directional "Yagi" antenna (model RA-4B, also manufactured by Telonics, Inc.[1]) attached to a 3 m mast. When a signal was received, the gain on the receiver was reduced to help in locating the position of the fish. A reduction in signal strength while slowly motoring in the direction of the signal was an indication that the fish had been passed over. Equal signal strength in all directions verified the position of the fish. In addition, an attempt was made to locate each fish visually after the electronic location was determined.

Latitude and longitude to the nearest one hundredth (0.01) of a minute was determined for each located fish using a portable global positioning system (GPS-50 Personal Navigator manufactured by Garmin International, Inc.[2]).

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[1] Telonics, Inc., 932 E. Impala Ave., Mesa, AZ.

[2] Garmin International, Inc., 11206 Thompson Ave., Lenexa, KS.

Latitude and longitude was determined for the same landmark at the beginning of each tracking event to verify the precision of the GPS-50. The locations of each fish were plotted on maps of Harding Lake derived from a USGS 1:63,360 map overlaid with a grid of latitude to the nearest five hundredth (0.05) of a minute and longitude to the nearest twelve hundredth (0.12) of a minute. In addition, water depth ($\leq$ 1 m, > 1 m to < 3 m, or $\geq$ 3 m), and vegetation type (none, submergent, or emergent) were recorded.

Data Analysis

Digitized maps of Harding Lake were constructed using Freelance (Lotus Development Corp.[3]). The 3 m depth contour and emergent vegetation zones were included on the maps. All fish were plotted on a single map for each tracking event. Locations of fish tracked daily from 8 June to 2 July are in Appendix A, and locations of fish tracked weekly, bi-weekly, and monthly appear in Appendix B. Movement was calculated as the straight line distance between the locations of a fish at the start and end of an interval. Intervals were 1-day, 3-days, and 7-days from 8 June to 2 July, 1992. Intervals were chosen as representative of typical hiatus lengths between first and second events of two-event mark-recapture experiments. These distances were considered the minimum distance moved during that interval. For example, the movements for the 3-day intervals were calculated as the straight line distances from the locations on day one to the locations on day three, from day two to day four, and every three day interval thereafter. This is different than adding three daily distances to get the movements during a 3-day interval. Simply adding three daily movements to determine the distance moved between 3-day intervals would have inflated expected movements because there was substantial back and forth movement and therefore would not be straight line distances.

The distance between locations at the start and end of an interval was calculated as follows:

$$m_{ijk} = \text{sqrt}[((lat_{ijk} - lat_{ijk-1}) * 1.86\ \text{km})^2 + [((long_{ijk} - long_{ijk-1}) * 0.80\ \text{km})^2] \quad (1)$$

where:

m_{ijk} = the distance the i^{th} fish moved during the j^{th} interval, during the k^{th} observation;

lat_{ijk} = the latitude of the i^{th} fish during the j^{th} time interval, during the k^{th} observation;

$long_{ijk}$ = the longitude of the i^{th} fish during the j^{th} time interval, during the k^{th} observation;

[3] Lotus Development Corporation, 55 Cambridge Parkway, Cambridge, MA.

1.86 km = the distance of one minute of latitude; and,

0.80 km = the distance of one minute of longitude measured at the 64th parallel.

The mean distances between locations at the start and end of each interval (1-day, 3-day, or 7-day) were calculated as follows:

$$\bar{m}_{ij} = \frac{\sum_{k=1}^{r} m_{ijk}}{r} ; \qquad (2)$$

where: $\bar{m}_{ij}$ = the mean distance travelled by the i^{th} fish during the j^{th} time interval;

r = the number of observations per fish and time interval.

The mean distance moved was calculated by interval for the groups of: (1) all fish; (2) small fish (450 - 585 mm FL); (3) large fish (> 585 mm FL); (4) males; (5) females; (6) small males; (7) small females; (8) large males; and, (9) large females as follows:

$$\bar{m}_{gj} = \frac{\sum_{i=1}^{t} \bar{m}_{gji}}{t} ; \qquad (3)$$

where: $\bar{m}_{gj}$ = the average distance fish of the g^{th} group moved for the j^{th} time interval;

t = the number of fish in the group.

The variance of m_{gj} was calculated as a two stage variance as:

$$V[\bar{m}_{gj}] = (1-f_1)\frac{s_1^2}{t} + f_1 \sum_{i=1}^{r} \frac{s_{2i}^2}{t^2 r_i} ; \qquad (4)$$

where:

$$s_{2i}^2 = \frac{\sum_{i=1}^{r} (m_{ijk} - \bar{m}_{ij})^2}{r - 1};$$

$$s_1^2 = \frac{\sum_{i=1}^{t} (m_{gji} - \bar{m}_{gj})^2}{t - 1};$$

$$f_1 = \frac{t}{N}; \text{ and,}$$

N = the number of fish in the population.

Distribution in relation to type of vegetation (none, submergent, or emergent) and water depth ($\leq$ 1 m, > 1 m to < 3 m, or $\geq$ 3 m) was calculated as the proportion of northern pike located in that habitat type by day and group as:

$$\hat{p}_{dgh} = \frac{x_{dgh}}{n_{dgh}} \qquad (5)$$

where:

$\hat{p}_{dgh}$ = the proportion of northern pike in the g^{th} group located within the h^{th} habitat type on the d^{th} day;

x_{dgh} = the number of observations of northern pike in the g^{th} group in the h^{th} habitat type on the d^{th} day; and,

n_{dgh} = the number of observations per group and habitat type on the d^{th} day.

Variance of this proportion was estimated as:

$$V[\hat{p}_{dgh}] = \frac{p_{gh}(1 - p_{gh})}{n - 1}. \qquad (6)$$

The average proportion of northern pike in a habitat type was calculated by group as:

$$\bar{P}_g = \frac{\sum_{d=1}^{D} \hat{p}_{dgh}}{D} ; \quad (7)$$

where: D = the number of days that the fish were located.

Variance of this average proportion was estimated as:

$$V[\bar{P}_g] = \frac{\sum_{d=1}^{D} V[\hat{p}_{gh}]}{D^2}. \quad (8)$$

RESULTS

Radio-tagged fish appeared to be in good condition when released after surgery and this was later verified by visual inspection of condition and sutures of eight of the radio-tagged fish that were recaptured in gill nets one to two weeks after implantation. There was no indication of external infection and the incisions were healing. All radio-tagged fish visually located during tracking events, also, appeared to be in good condition.

The mean fork-length of the male fish used in this study was 582 mm (range, 440 - 725 mm), and the mean fork-length of the female fish was 599 mm (range, 470 - 722 mm) (Table 2). A total of 584 relocations were determined from 8 June through 2 July, 90 relocations from 6 July through 27 July, 22 relocations on 7 August, 20 relocations on 8 September, and 22 relocations on 30 September. Twenty-two of the 26 radio-tagged fish were followed for the duration of the study. Of the other four fish, one was recovered dead on 29 June, one radio-tag was found on the bottom of the lake in shallow water on 20 July, one fish was not located after 16 June, and one was not located after 6 July. The fate of the two missing radio-tags is not known. Fish were considered alive and still carrying transmitters when locations changed between tracking events. None of the fish remained at the same location for more than two consecutive tracking events.

Movements

8 June - 2 July, 1992:

Straight line distances for 1-day intervals for all fish ranged from no apparent movement to 3.25 km. The most active fish was a 670 mm female (tag number 409) that had a mean daily movement of 0.66 km (SE = 0.20 km). The least active fish was a 630 mm male (tag number 388) that had a mean daily

Table 2. Floy tag number, fork length, and sex of radio-tagged northern pike in Harding Lake.

Date Tagged	Floy Tag Number	Fork Length (mm)	Sex
26 May 1992	63979	615	M
26 May 1992	62770	682	M
26 May 1992	64943	637	M
26 May 1992	00378	440	M
26 May 1992	00380	584	M
26 May 1992	64020	597	M
26 May 1992	00384	471	M
26 May 1992	64423	479	M
26 May 1992	64874	613	M
26 May 1992	00383	601	M
26 May 1992	00388	630	M
27 May 1992	00390	537	F
27 May 1992	00391	628	F
27 May 1992	71271	642	F
27 May 1992	63808	722	F
27 May 1992	00353	568	F
27 May 1992	00352	510	M
27 May 1992	00356	570	F
28 May 1992	00373	563	M
28 May 1992	00409	670	F
28 May 1992	00412	571	F
28 May 1992	00408	538	F
28 May 1992	00422	579	F
28 May 1992	64041	691	F
28 May 1992	00428	470	F
29 May 1992	04272	725	M

movement of 0.15 km (SE = 0.02 km). The mean daily distance moved for all radio-tagged northern pike in Harding Lake between 8 June and 2 July 1992 was 0.33 km (SE = 0.02 km). When broken down by groups, the biggest difference in mean 1-day distance moved was between small males and small females (q = 14.22, $P < 0.001$); small males moved more than any other group and small females moved less than any other group (Table 3).

Straight line distances for 3-day intervals for all fish ranged from no apparent movement to 3.20 km. The most active fish was a 584 mm male (tag number 00380) that had a mean 3-day movement of 0.79 km (SE = 0.26 km). The least active fish was a 630 mm male (tag number 388) that had a mean 3-day movement of 0.17 km (SE = 0.02 km). The mean 3-day distance moved for all radio-tagged northern pike in Harding Lake between 8 June and 2 July 1992 was 0.44 km (SE = 0.03 km). When broken down by groups, the biggest difference in mean 3-day distance moved was between small males and small females (q = 4.53, $P < 0.01$); small males moved more than any other group and small females moved less than any other group (Table 3).

Straight line distances for 7-day intervals for all fish ranged from 0.01 to 3.06 km. The most active fish was a 597 mm male (tag number 64020) that had a mean 7-day movement of 1.58 km (SE = 0.37 km). The least active fish was a 568 mm female (tag number 353) that had a mean 7-day movement of 0.24 km (SE = 0.06 km). The mean 7-day distance moved for all radio-tagged northern pike in Harding Lake between 8 June and 2 July 1992 was 0.59 km (SE = 0.03 km). When broken down by groups, the biggest difference in mean 7-day distance moved was between small females and large males (q = 9.82, $P < 0.001$); small females moved less than any other group and large males moved more than any other group (Table 3).

Half of the radio-tagged northern pike moved at least a mean distance of 0.29 km between 1-day intervals, 0.33 km between 3-day intervals, and 0.47 km between 7-day intervals (Figure 3). When broken down by time segments within June, the most active period (determined by the median of the mean distances) was between 22 and 28 June except for large females, which were most active between 8 and 14 June. The least active period for all fish was between 15 and 21 June (Table 4).

Water Depth and Vegetation

8 June - 2 July, 1992:

During the period 8 June through 2 July all radio-tagged northern pike were located in water depth < 3 m. The proportion of radio-tagged fish found in water depth ≤ 1 m was 0.95 (SE = 0.04); males at a higher proportion than females (Z = 3.26, $P < 0.01$), and small females at a higher proportion than large females (Z = 2.35, $P < 0.01$) (Table 5). Seven males were always found in water depth ≤ 1 m. A 691 mm female (tag number 64041) was located in water depth > 1 m more often than any other radio-tagged fish.

Overall, during this period, a higher proportion of northern pike were located in emergent vegetation (0.75; SE = 0.03); males at a higher proportion than females (Z = 8.21, $P < 0.01$), and large males at a higher proportion than

Table 3. Mean straight line distances (km) radio-tagged northern pike moved in Harding Lake from 8 June to 2 July 1992 between one, three, and seven-day intervals.

Interval Group	Distance (km)		Total Number	
	Mean	SE	Number of Fish	Consecutive Locations
1-day				
All Fish	0.33	0.02	26	457
Females	0.30	0.04	12	217
Males	0.36	0.04	14	240
Large	0.33	0.04	13	217
Small	0.34	0.04	13	240
Large Males	0.29	0.04	8	133
Small Males	0.46	0.06	6	107
Large Females	0.39	0.08	5	84
Small Females	0.23	0.02	7	133
3-day				
All Fish	0.44	0.03	26	428
Females	0.42	0.04	12	206
Males	0.46	0.05	14	222
Large	0.46	0.05	13	202
Small	0.42	0.04	13	226
Large Males	0.42	0.08	8	122
Small Males	0.51	0.08	6	100
Large Females	0.51	0.07	5	80
Small Females	0.35	0.06	7	126
7-day				
All Fish	0.59	0.03	26	379
Females	0.52	0.08	12	184
Males	0.65	0.08	14	195
Large	0.68	0.10	13	179
Small	0.50	0.05	13	200
Large Males	0.69	0.15	8	107
Small Males	0.59	0.07	6	88
Large Females	0.65	0.18	5	72
Small Females	0.43	0.08	7	112

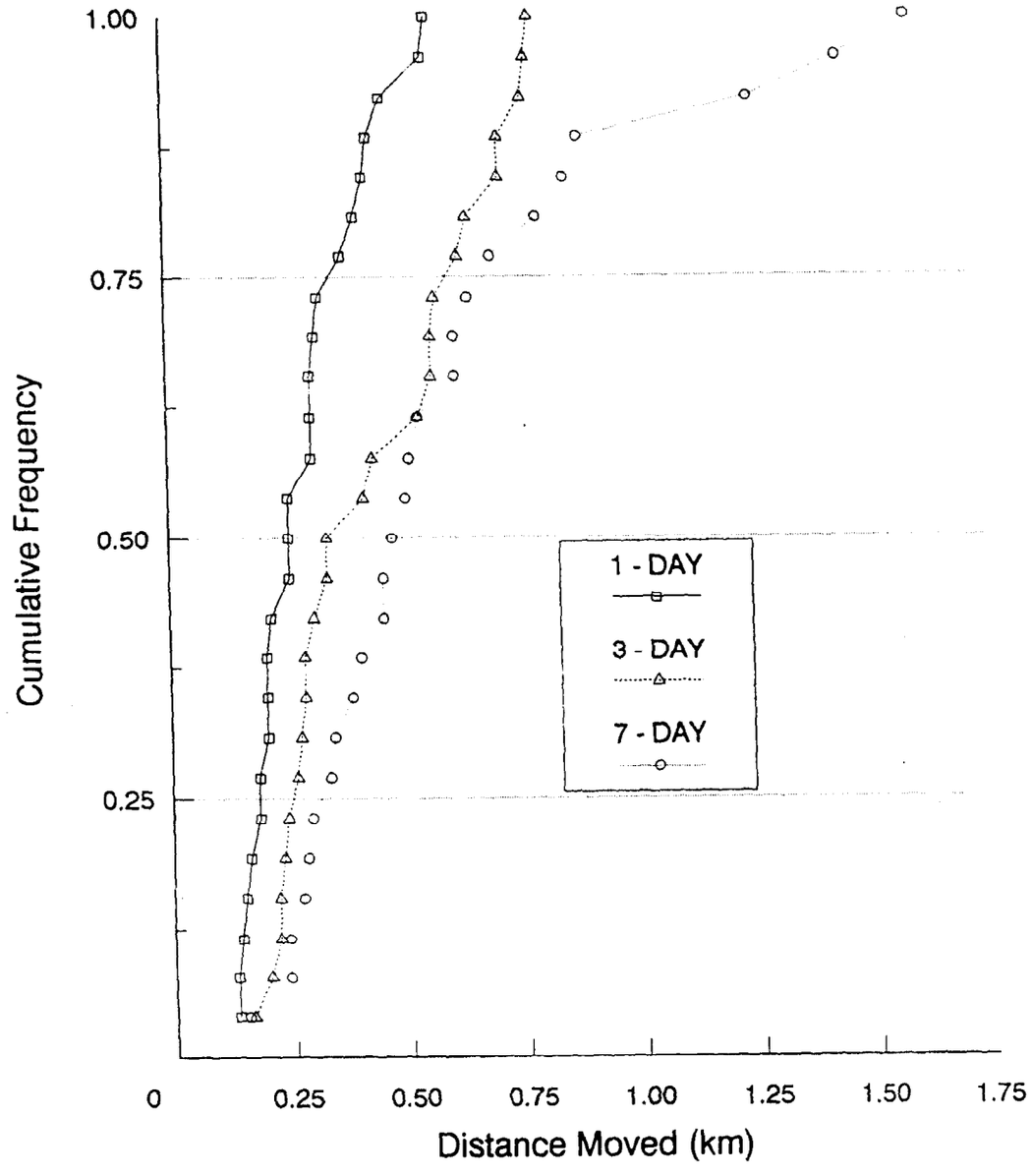

Figure 3. Cumulative frequencies of mean distance moved for 26 radio-tagged northern pike in Harding Lake between one, three, and seven-day intervals.

Table 4. Median straight line daily distances (km) radio-tagged northern pike moved in Harding Lake during four time periods from 8 June to 2 July 1992.

Group	Time Periods			
	1st[a]	2nd[b]	3rd[c]	4th[d]
All Fish	0.18	0.11	0.26	0.19
Males	0.17	0.11	0.26	0.21
Females	0.20	0.10	0.26	0.15
Large	0.14	0.11	0.24	0.20
Small	0.22	0.10	0.41	0.15
Large Males	0.12	0.12	0.24	0.21
Small Males	0.63	0.12	0.42	0.21
Large Females	0.46	0.08	0.23	0.14
Small Females	0.15	0.10	0.37	0.15

[a] 8 June through 14 June 1992.
[b] 15 June through 21 June 1992.
[c] 22 June through 28 June 1992.
[d] 29 June through 2 July 1992.

Table 5. Observed proportion of radio-tagged northern pike in Harding Lake by water depth from 8 June to 2 July 1992.

	Water Depth (m)		
	≤ 1	>1 <3	≥3
All	0.95	0.05	0.00
Male Fish	0.98	0.02	0.00
Female Fish	0.92	0.08	0.00
Large Fish	0.94	0.06	0.00
Small Fish	0.96	0.04	0.00
Large Male	0.98	0.02	0.00
Small Male	0.98	0.02	0.00
Large Female	0.87	0.13	0.00
Small Female	0.95	0.05	0.00

small males ($Z = 2.63$, $P < 0.01$) (Table 6). Seven males were always found in emergent vegetation. The fish located the least in vegetation was a 628 mm female (tag number 391). When broken down by time segments northern pike were located in vegetated areas at a higher proportion from 29 June to 2 July than other time segments in June ($Z = 8.21$, $P < 0.01$) (Figure 4).

6 July - 30 September, 1992:

During the period 6 July through 30 September the proportion of radio-tagged northern pike in water depth ≥ 3 m was 0.15 (SE = 0.07). During this period, however, a large proportion (0.70; SE = 0.05) of radio-tagged northern pike continued to be located in water depth ≤ 1 m. Contrary to the period 8 June through 2 July, large females were located at a higher proportion in water depth ≤ 1 m than small females ($Z = 8.21$, $P < 0.01$) . Males were located at a higher proportion than females ($Z = 3.12$, $P < 0.01$), large fish at a higher proportion than small fish ($Z = 3.46$, $P < 0.01$), and large males at a higher proportion than small males ($Z = 3.33$, $P < 0.01$) (Table 7).

Radio-tagged northern pike began moving into water ≥ 3 m in July. This trend continued through 8 September at a peak proportion of 0.40 (SE = 0.10) radio-tagged fish located in water depth ≥ 3 m (Table 8). All groups did not move into deep water at the same time. Large males moved into water depth ≥ 3 m in July and were followed by small males in August. Females did not move into deep water until September. All small males moved back into water depth less than 3 m late in September (Figure 5). During this period, northern pike moved away from areas with emergent vegetation; large males more quickly than other groups (Figure 6). Males were found at a higher proportion in emergent vegetation than females ($Z = 2.48$, $P < 0.02$) (Table 9).

DISCUSSION

Northern pike in Harding Lake disperse to deeper areas of the lake later than northern pike of other interior lakes. Pearse and Clark (1992) found a substantial portion of radio-tagged northern pike in water depth > 3 m throughout June in Volkmar Lake. However, all radio-tagged northern pike in Harding Lake remained in water depth < 3 m until July. This suggests that the current methods used to capture northern pike (Skaugstad and Burkholder 1992) would be more difficult after June but still viable throughout the month of June in Harding Lake (Figure 7). The data do not indicate that early June is better than late June for sampling northern pike in Harding Lake (Figure 8).

This study supports the recommendation of Skaugstad and Burkholder (1992) that future northern pike mark-recapture experiments in Harding Lake be delayed until the lake is completely ice-free. The results of this study indicate an increasing trend through June of northern pike movement into vegetated areas after the ice melts. This trend is supported, although the dates are not directly comparable, by the daily capture rates of the mark-recapture experiments for northern pike in Harding Lake (Burkholder 1990, and Skaugstad and Burkholder 1992). The average number of fish captured per day using similar gear at similar depths increased substantially from the first events

Table 6. Observed proportion of radio-tagged northern pike in Harding Lake by vegetation type from 8 June to 2 July 1992.

	Vegetation Type		
	None	Submergent	Emergent
All	0.22	0.03	0.75
Male Fish	0.10	0.01	0.89
Female Fish	0.36	0.05	0.59
Large Fish	0.24	0.01	0.75
Small Fish	0.21	0.04	0.75
Large Male	0.07	0.00	0.93
Small Male	0.14	0.03	0.83
Large Female	0.28	0.02	0.70
Small Female	0.27	0.06	0.67

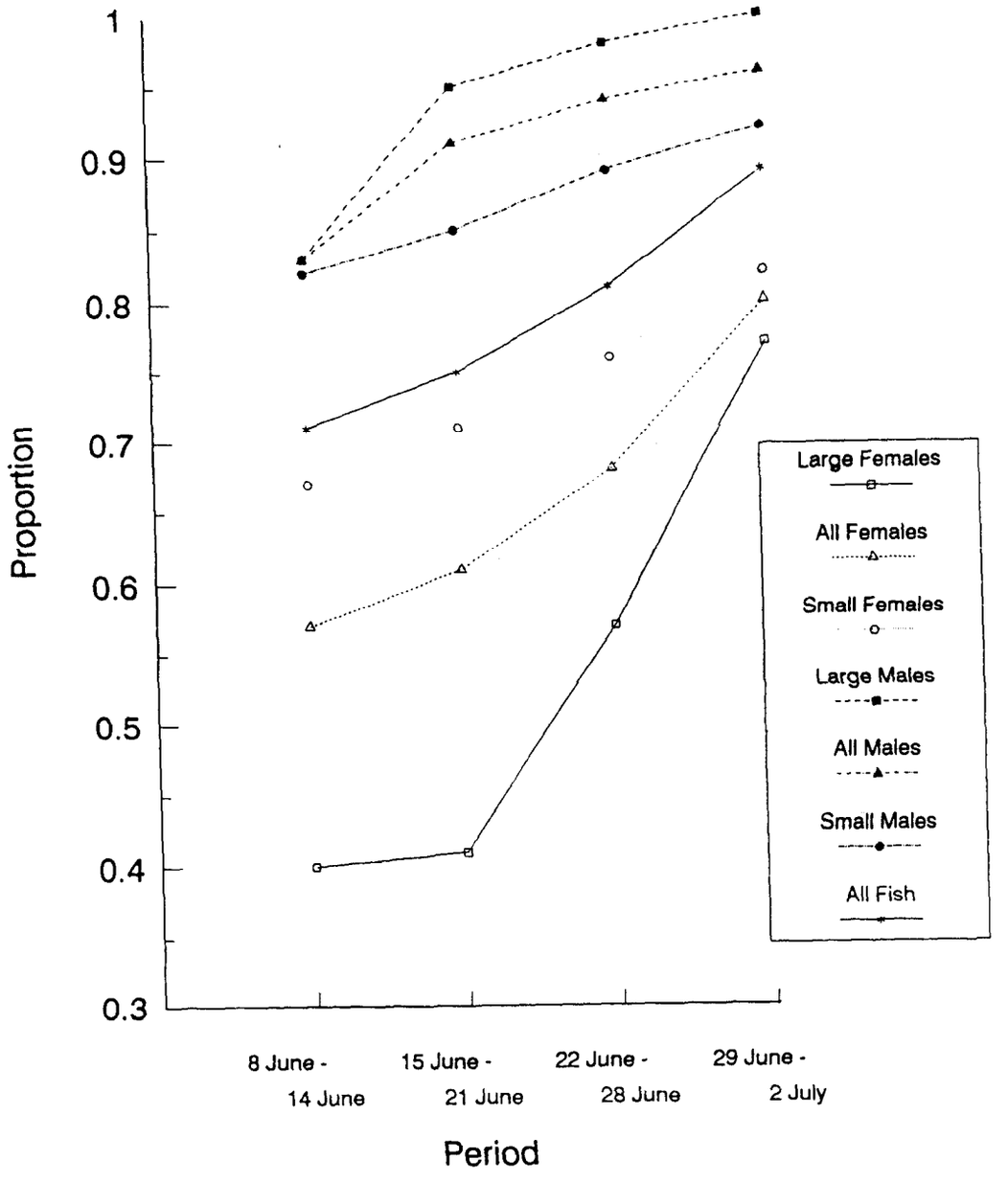

Figure 4. Proportion of radio-tagged northern pike found in vegetation in Harding Lake during four periods from 8 June to 2 July 1992.

Table 7. Observed proportion of radio-tagged northern pike in Harding Lake by water depth from 6 July to 30 September 1992.

	Water Depth (m)		
	≤ 1	>1 <3	≥3
All	0.70	0.15	0.15
Male Fish	0.68	0.08	0.24
Female Fish	0.72	0.22	0.06
Large Fish	0.68	0.06	0.26
Small Fish	0.72	0.22	0.06
Large Male	0.56	0.05	0.39
Small Male	0.80	0.12	0.08
Large Female	0.86	0.07	0.07
Small Female	0.64	0.32	0.04

Table 8. Observed proportion of northern pike in Harding Lake found in water depth ≥ 3 m during five time periods from 8 June to 30 September 1992.

Group	Time Periods				
	1st[a]	2nd[b]	3rd[c]	4th[d]	5th[e]
All Fish	0.00	0.03	0.32	0.40	0.28
Males	0.00	0.06	0.58	0.50	0.33
Females	0.00	0.00	0.00	0.20	0.20
Large	0.00	0.08	0.50	0.55	0.50
Small	0.00	0.00	0.17	0.18	0.08
Large Males	0.00	0.13	0.83	0.80	0.67
Small Males	0.00	0.00	0.33	0.20	0.00
Large Females	0.00	0.00	0.00	0.25	0.25
Small Females	0.00	0.00	0.00	0.17	0.17

[a] 8 June through 2 July 1992.
[b] 6 July through 27 July 1992.
[c] 7 August 1992.
[d] 8 September 1992.
[e] 30 September 1992.

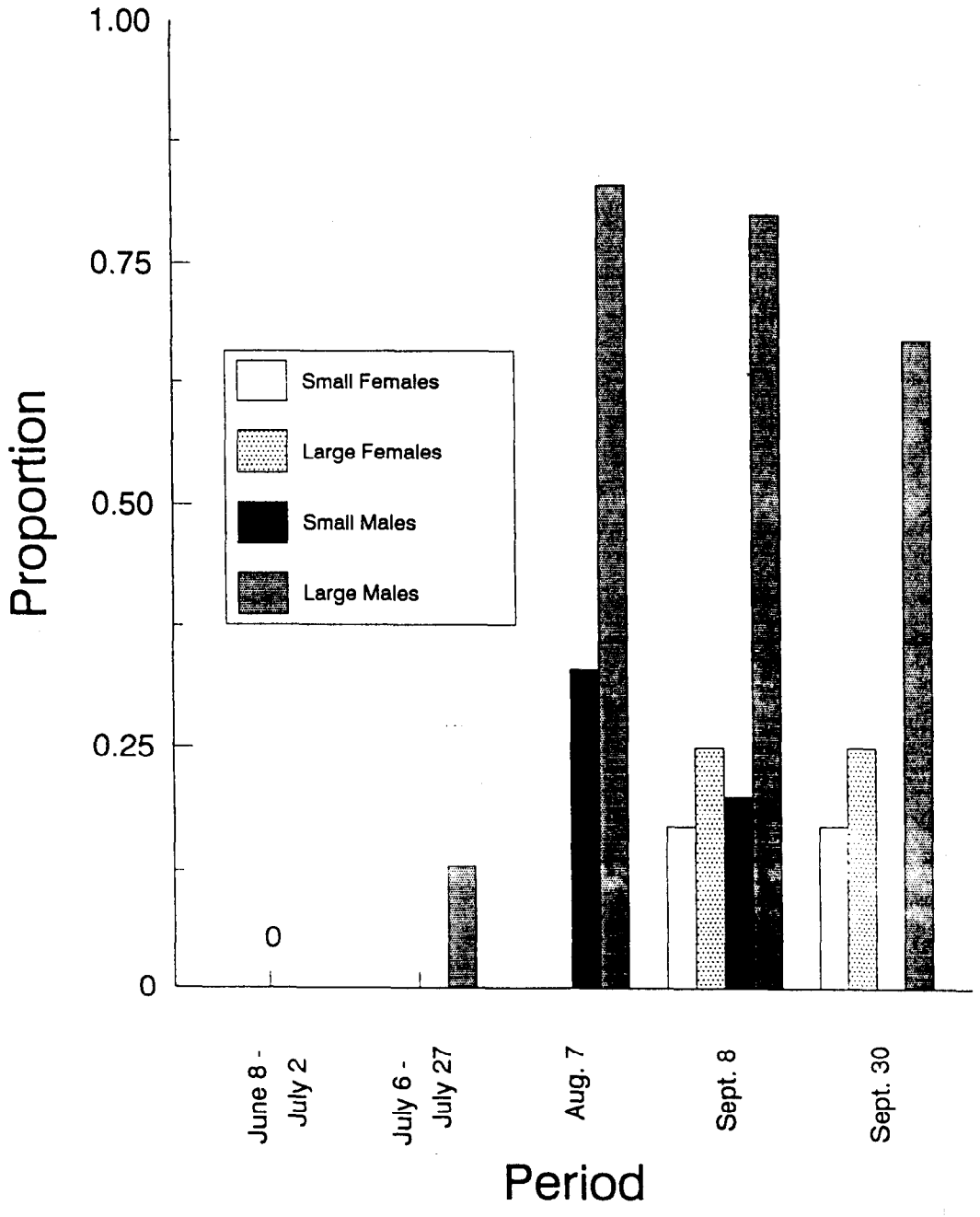

Figure 5. Proportion of radio-tagged northern pike found in 3 m water depth and deeper in Harding Lake during five periods from 8 June to 30 September 1992.

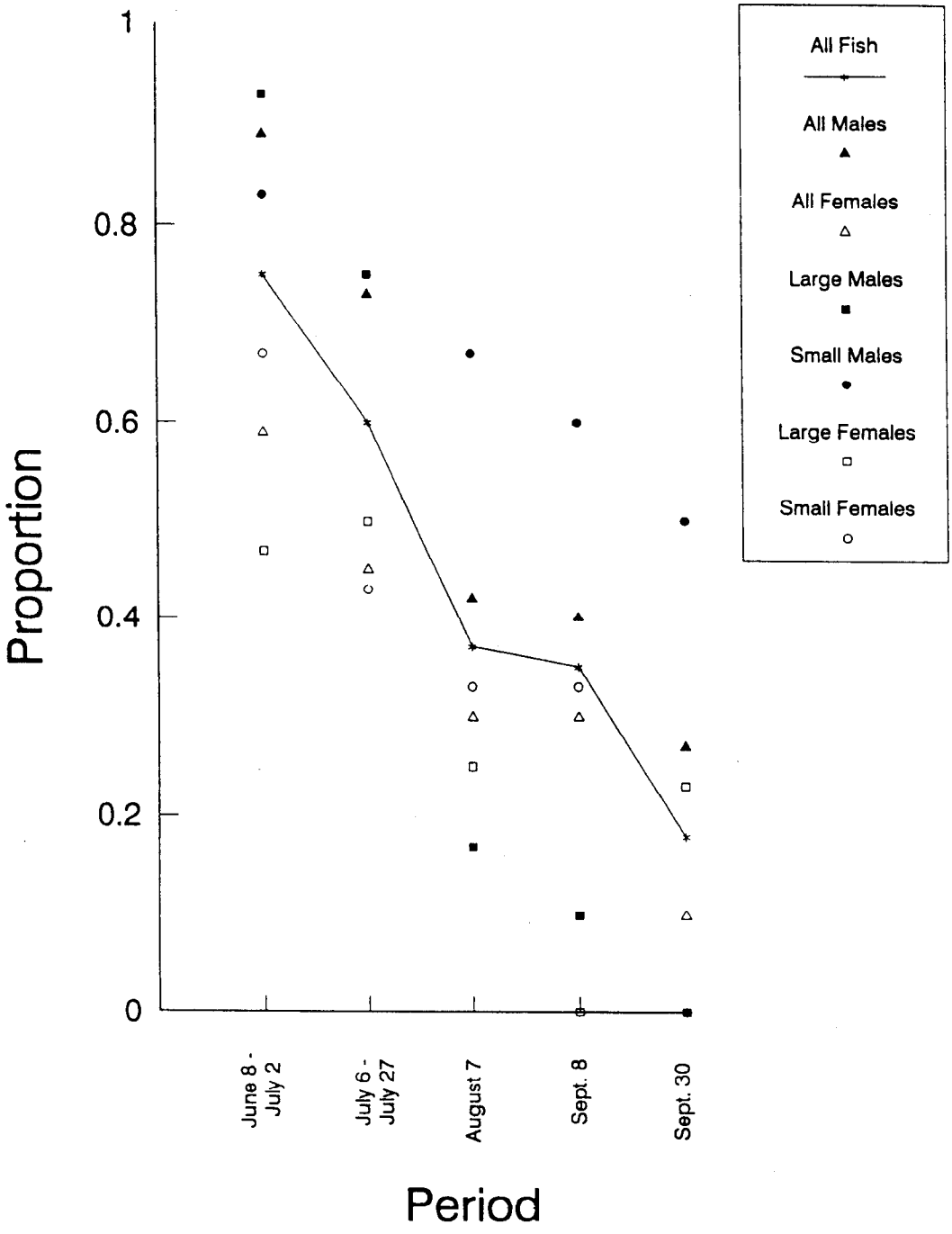

Figure 6. Proportion of radio-tagged northern pike found in emergent vegetation in Harding Lake during five periods from 8 June to 30 September 1992.

Table 9. Observed proportion of radio-tagged northern pike in Harding Lake by vegetation type from 6 July to 30 September 1992.

	Vegetation Type		
	None	Submergent	Emergent
All	0.35	0.17	0.53
Male Fish	0.21	0.22	0.57
Female Fish	0.51	0.12	0.37
Large Fish	0.29	0.26	0.45
Small Fish	0.40	0.10	0.50
Large Male	0.20	0.32	0.48
Small Male	0.22	0.12	0.66
Large Female	0.43	0.18	0.39
Small Female	0.57	0.09	0.34

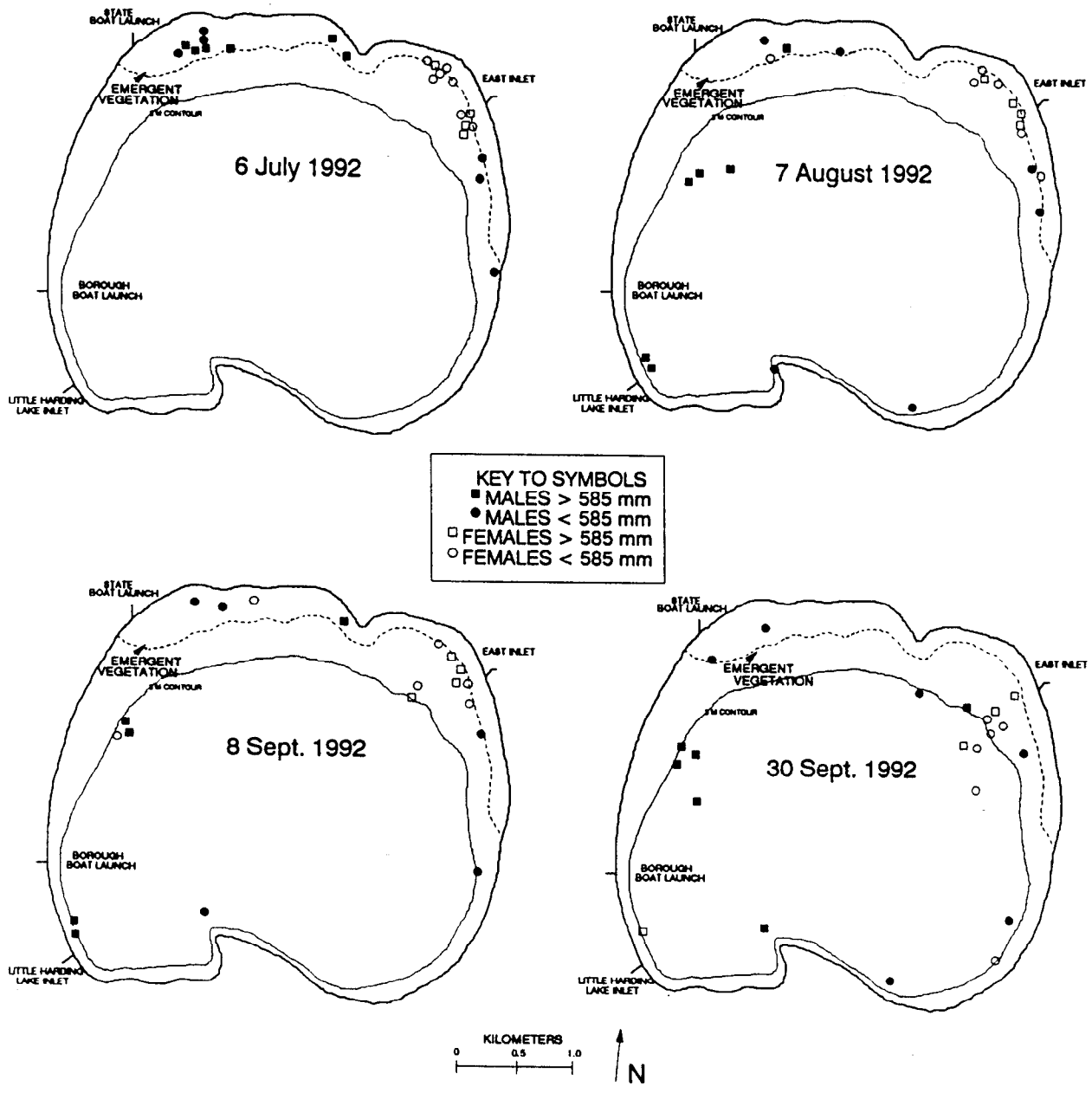

Figure 7. Locations of radio-tagged northern pike in Harding Lake on four different days between 6 July and 30 September 1992.

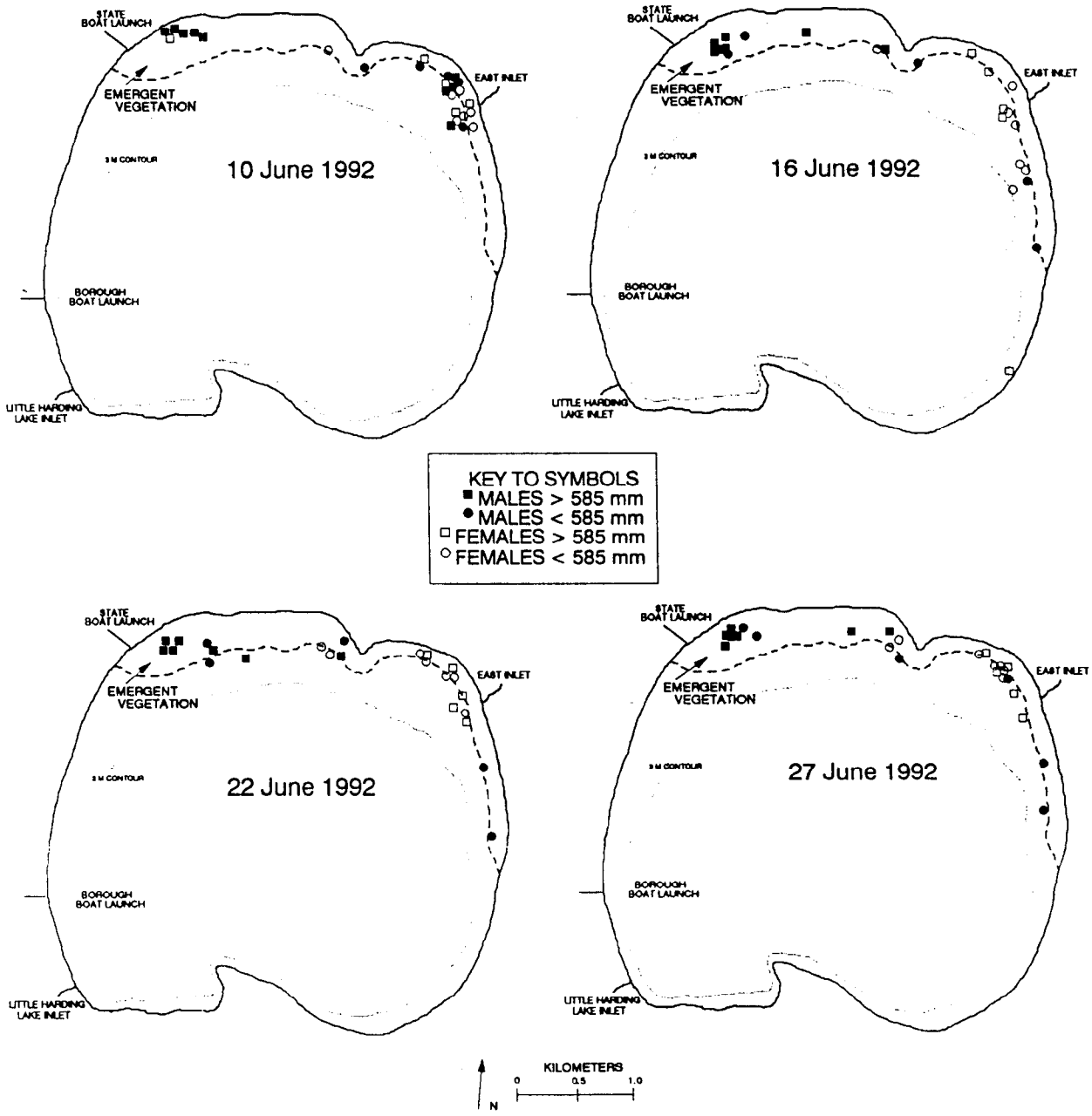

Figure 8. Locations of radio-tagged northern pike in Harding Lake on four days in June 1992.

to the second events during the Harding Lake mark-recapture experiments of 1990, 1991, and 1992.

Intraspecific variation in habitat use may be the cause of some of the size selectivity of past mark-recapture experiments for northern pike in Harding Lake. In particular, differences in habitat preference by sex and size may offer an explanation for the difference in size distribution of northern pike during the second event compared to the first event of the mark-recapture experiments. The present study shows a variation in habitat use between male and female northern pike, which is minimized as June progresses. This gives further strength to the notion that sampling may be improved and sampling bias reduced if mark-recapture dates are delayed.

The results of this study indicate that northern pike make small back-and-forth movements but not great straight line movements. In order to maximize mixing probabilities between the first and second event of mark-recapture experiments, it is necessary to set up sampling zones that are small enough to ensure that 50% of the fish marked in one zone will move to another zone during the hiatus. Considering the movements of the radio-tagged northern pike in Harding Lake, the inshore-length of these zones (pie slices) would need to be 0.29 km for a 1-day hiatus, 0.33 km for a 3-day hiatus, and 0.47 km for a 7-day hiatus. For a 7-day hiatus there would need to be 26 zones (the estimated perimeter of Harding Lake is 12.32 km).

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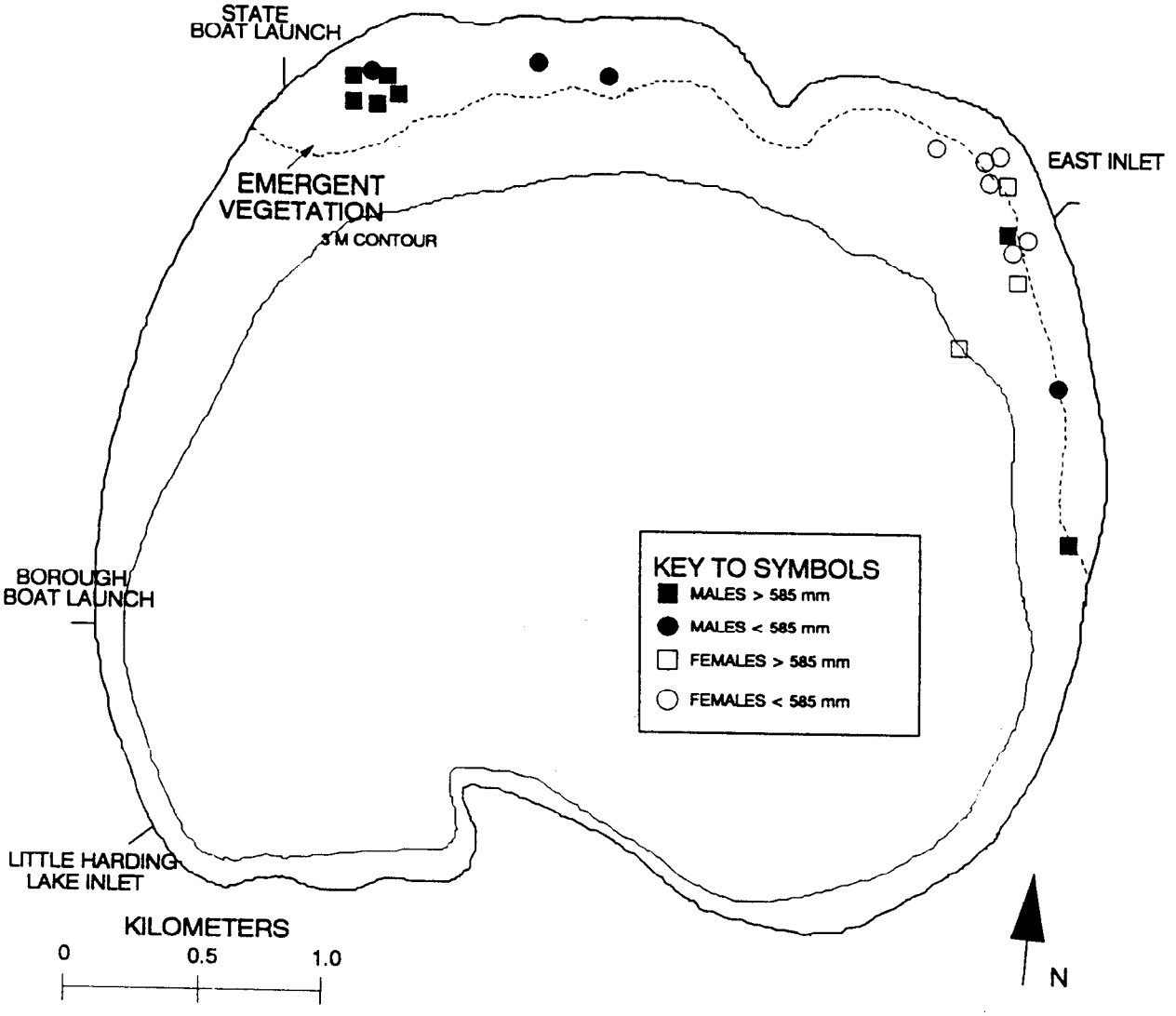
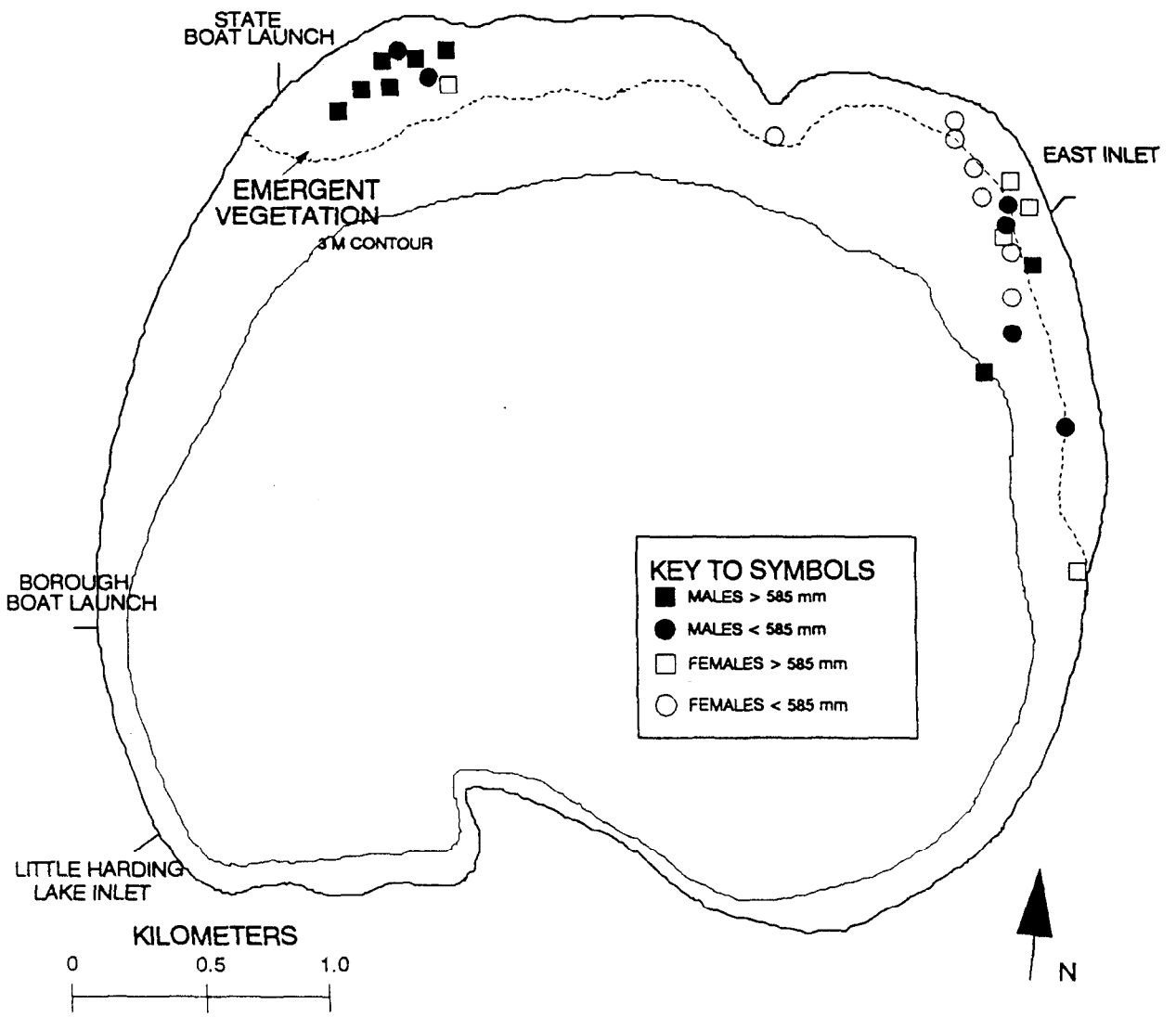
APPENDIX A

LOCATION OF FISH TRACKED DAILY FROM 8 JUNE TO 2 JULY

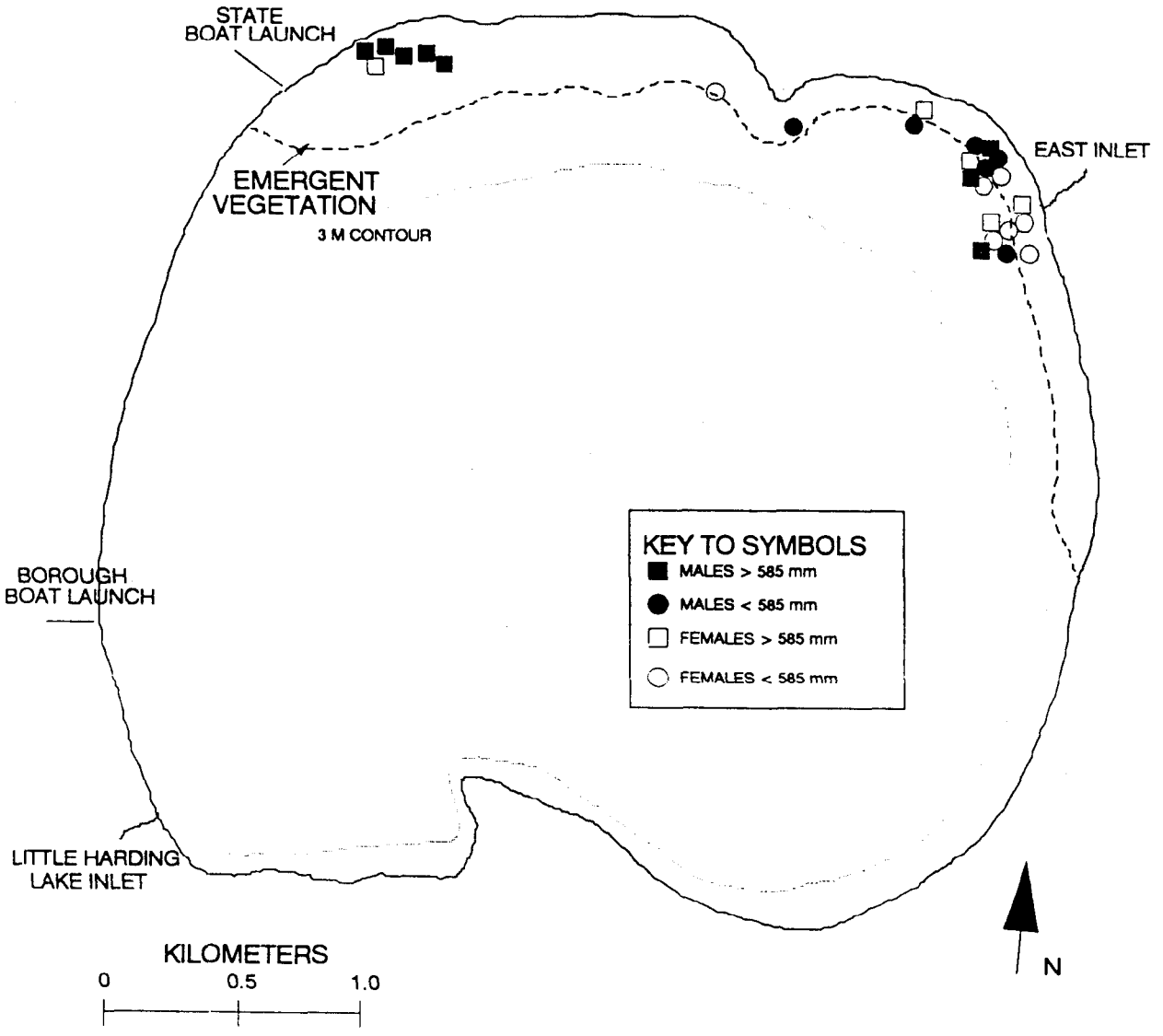
Appendix A1. Locations of radio-tagged northern pike on 8 June 1992 in Harding Lake.



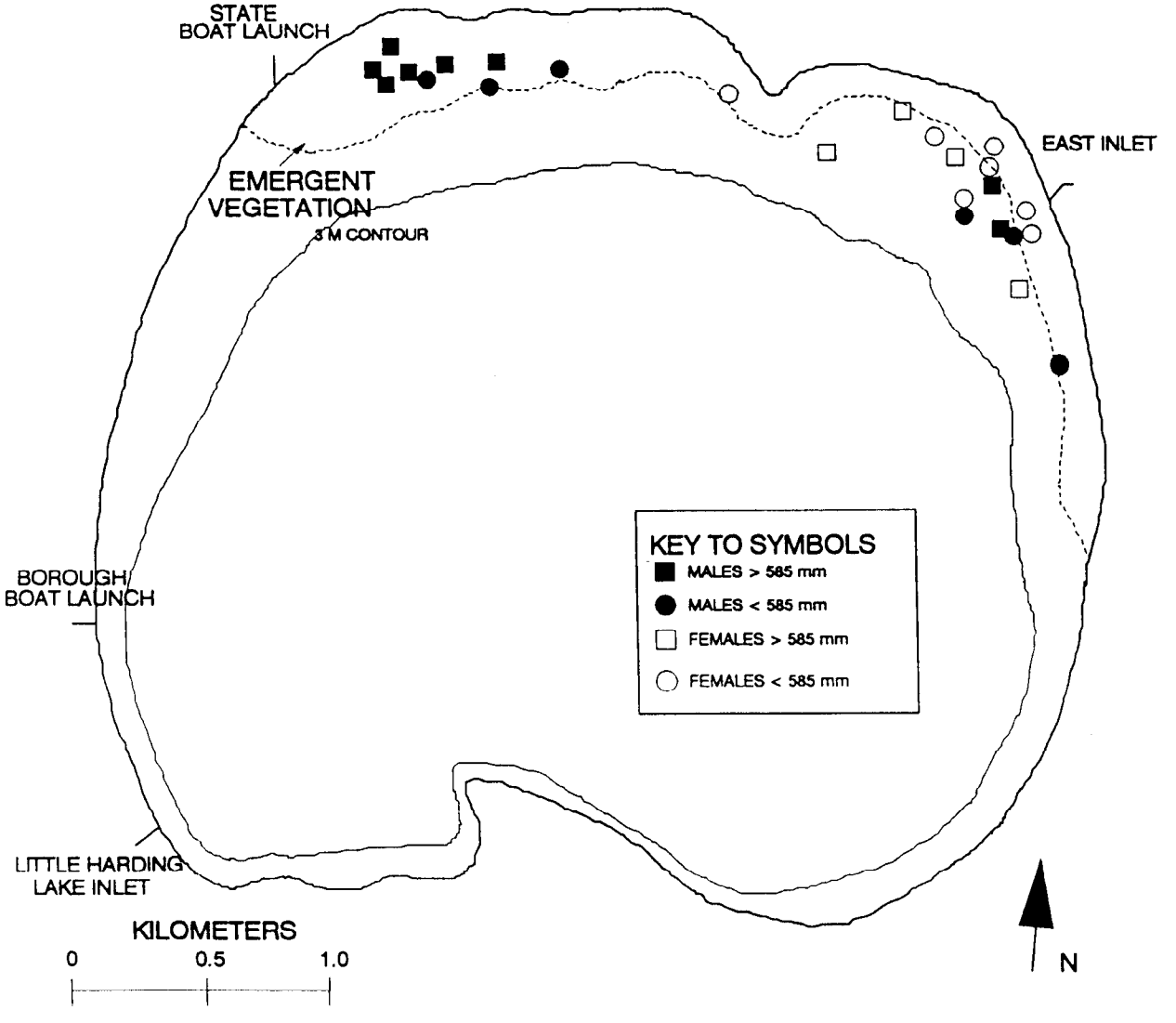
Appendix A2. Locations of radio-tagged northern pike on 9 June 1992 in Harding Lake.



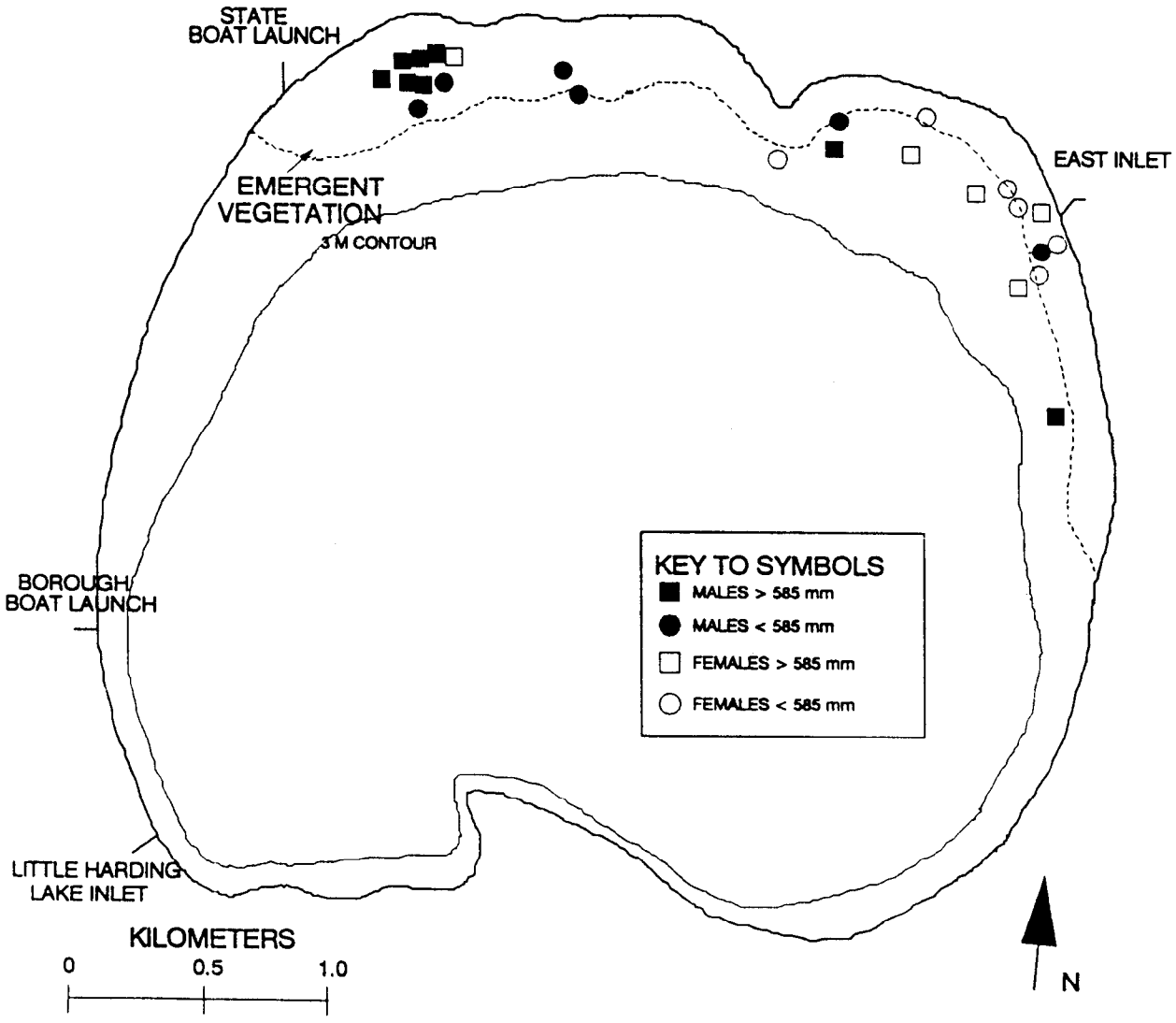
Appendix A3. Locations of radio-tagged northern pike on 10 June 1992 in Harding Lake.



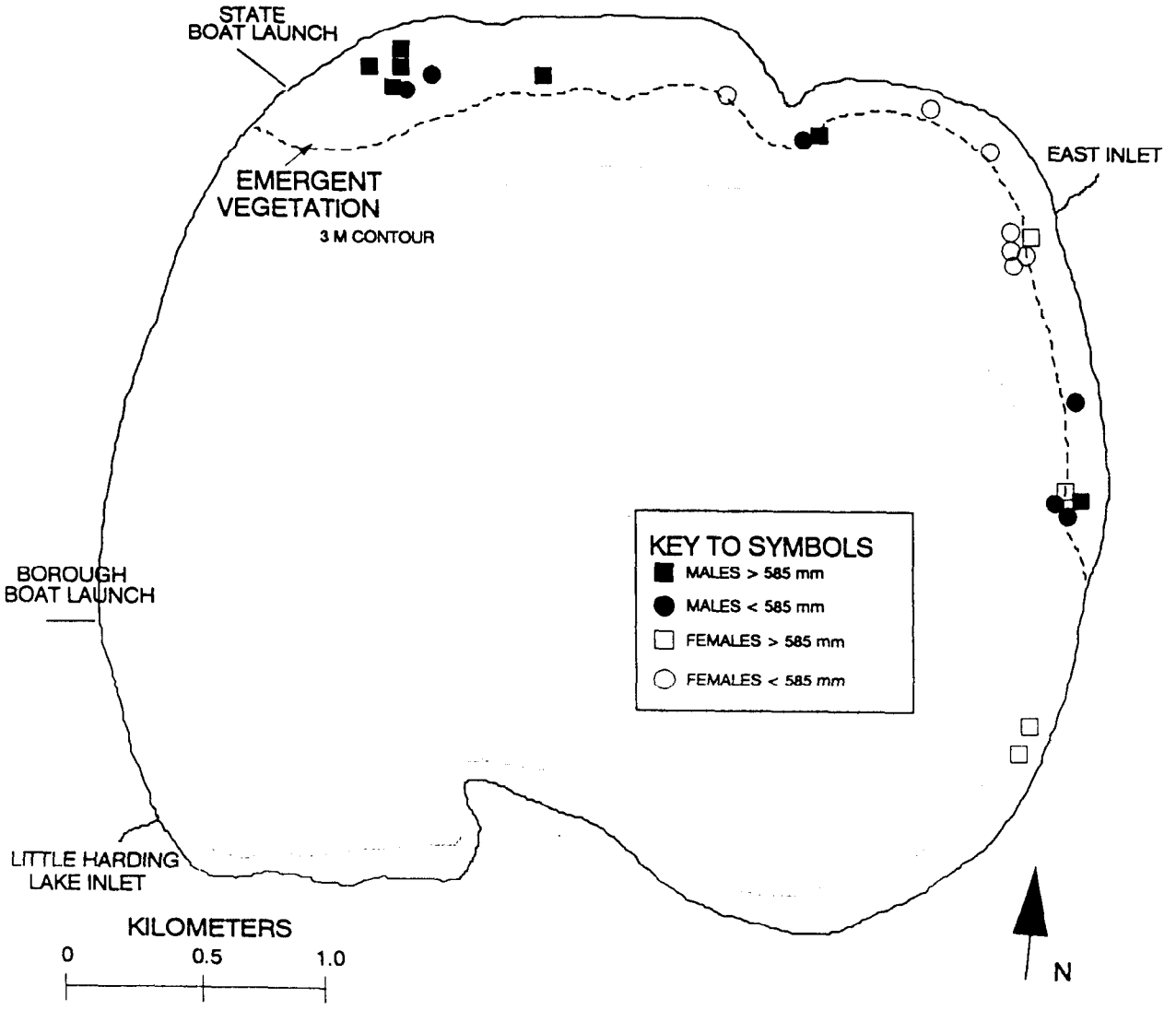
Appendix A4. Locations of radio-tagged northern pike on 11 June 1992 in Harding Lake.



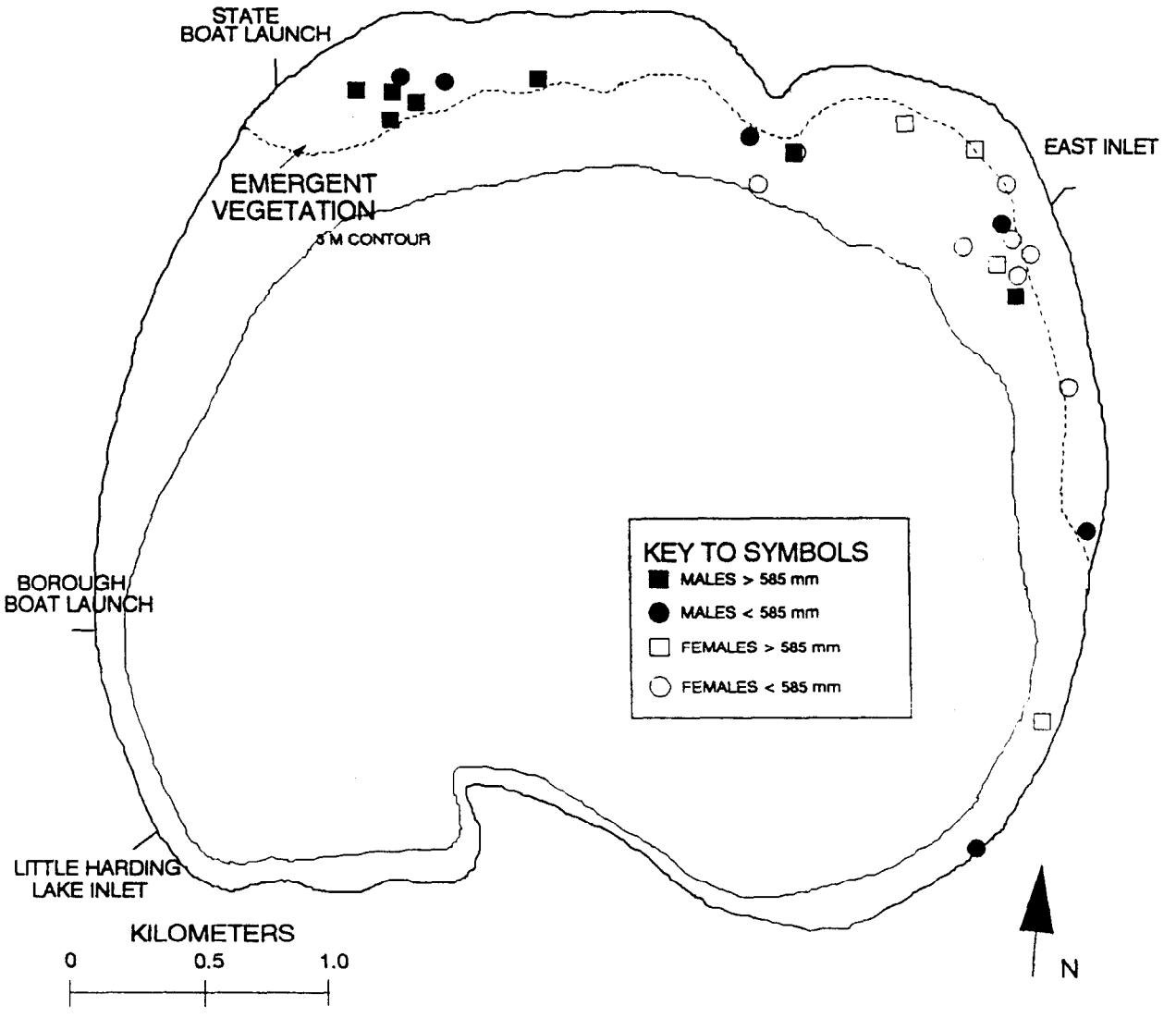
Appendix A5. Locations of radio-tagged northern pike on 12 June 1992 in Harding Lake.



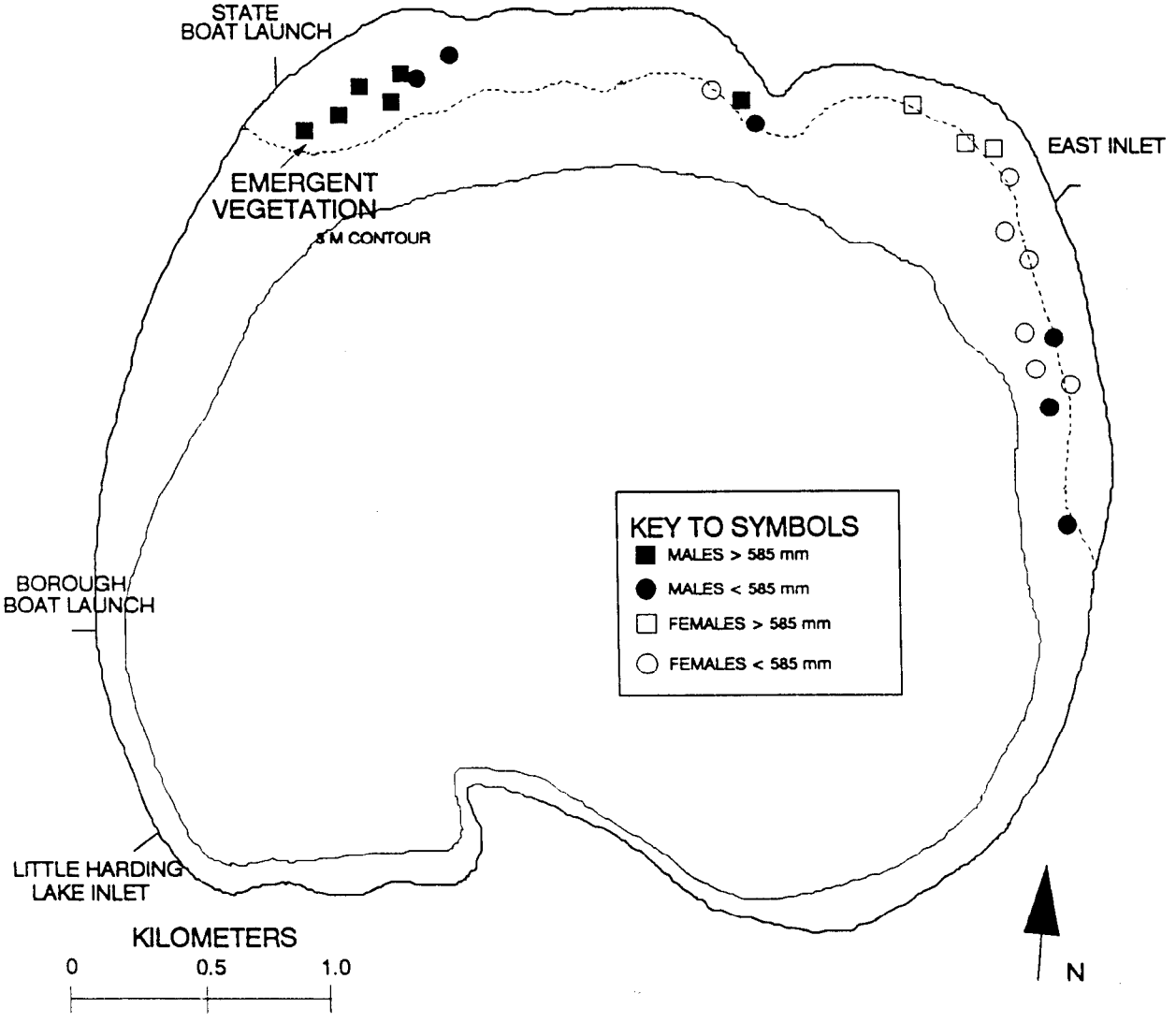
Appendix A6. Locations of radio-tagged northern pike on 13 June 1992 in Harding Lake.



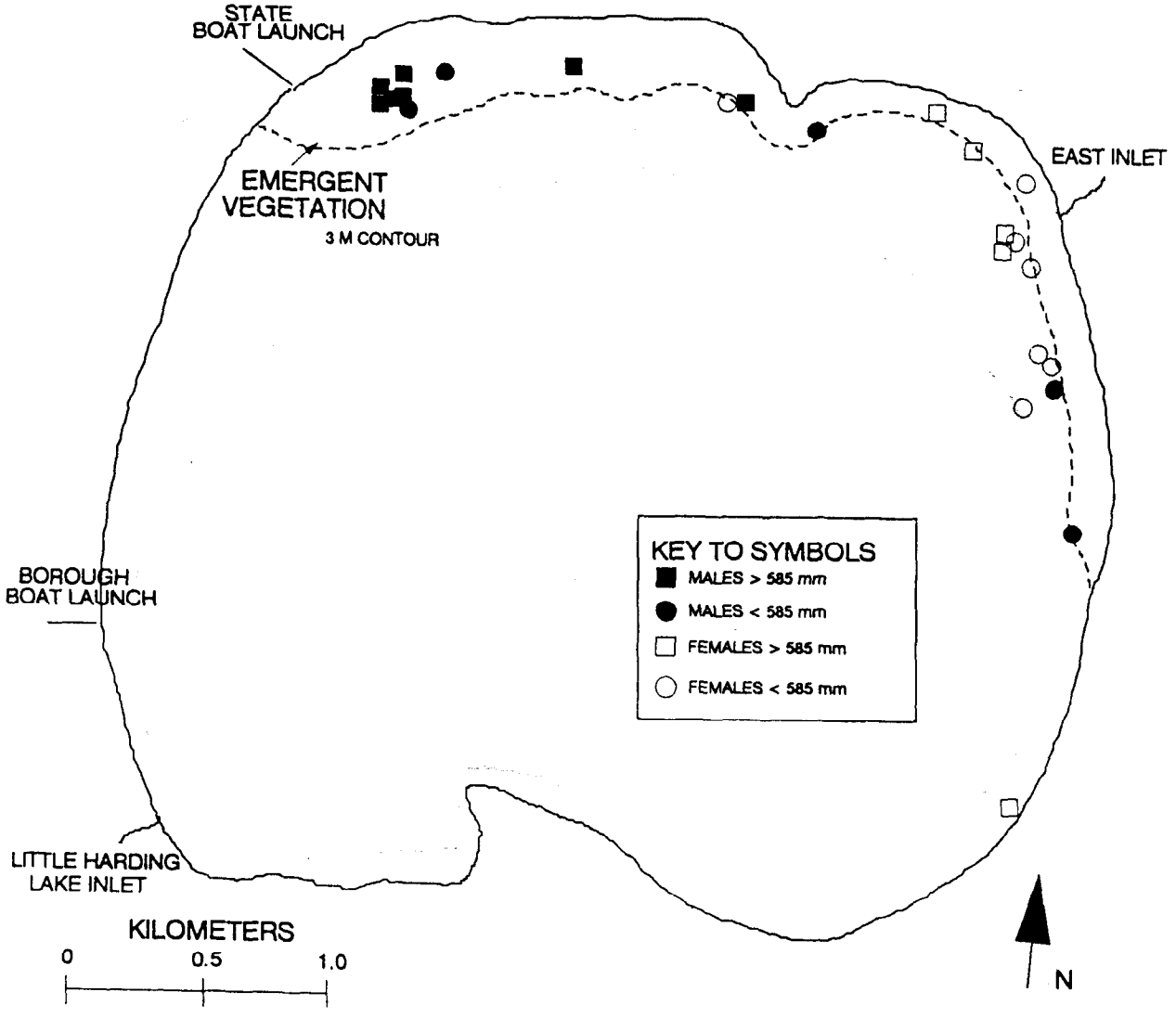
Appendix A7. Locations of radio-tagged northern pike on 14 June 1992 in Harding Lake.



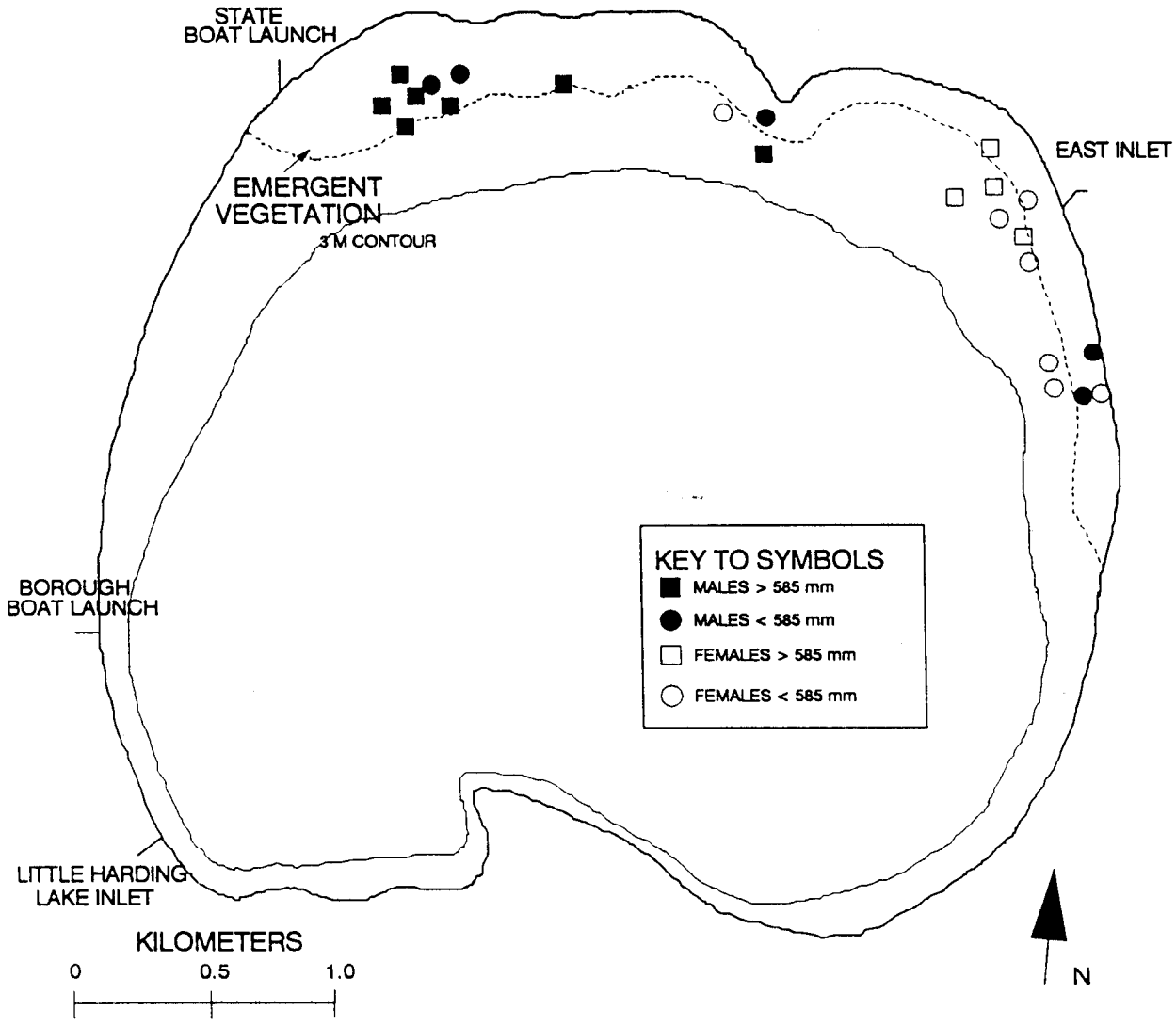
Appendix A8. Locations of radio-tagged northern pike on 15 June 1992 in Harding Lake.



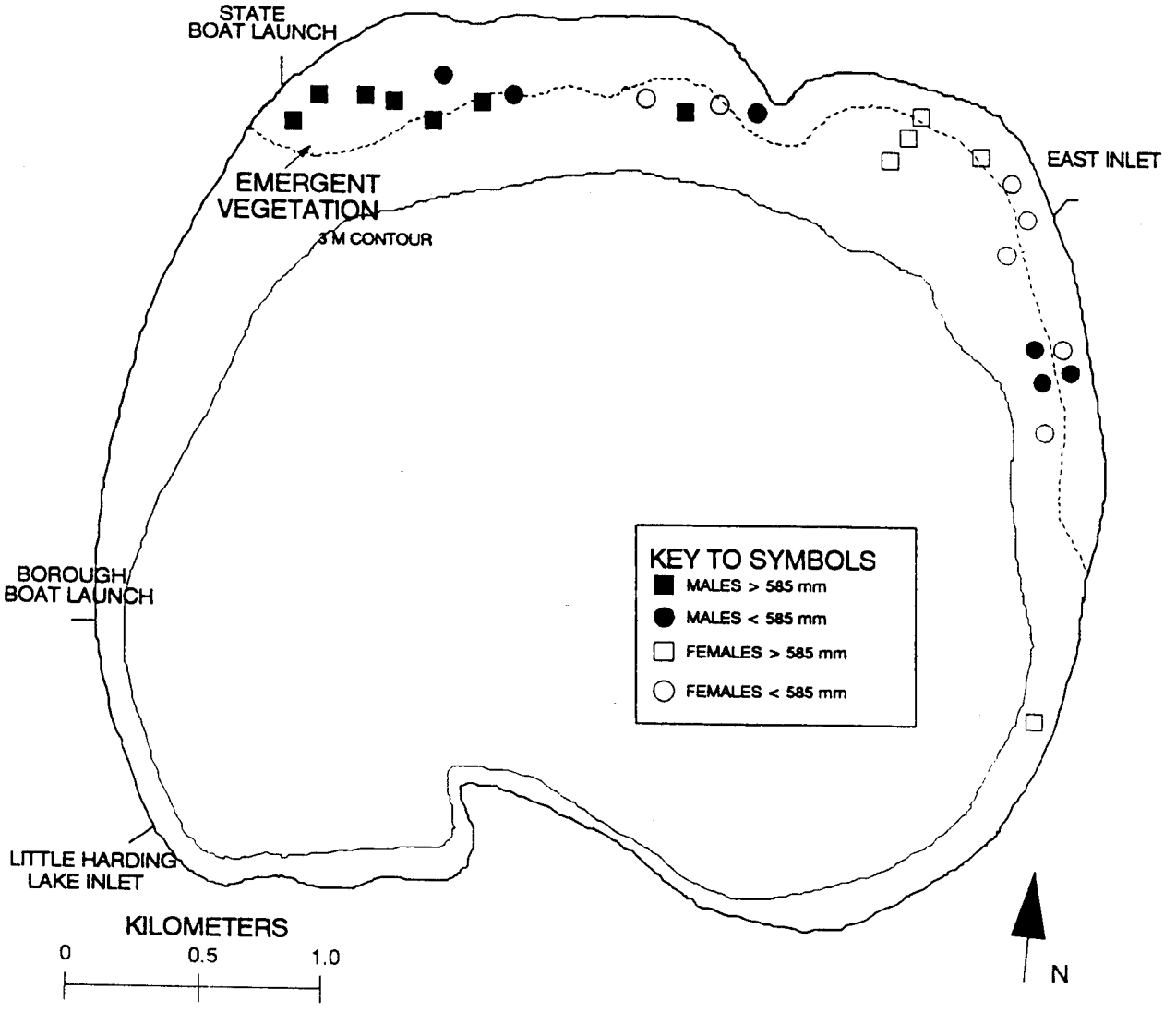
Appendix A9. Locations of radio-tagged northern pike on 16 June 1992 in Harding Lake.



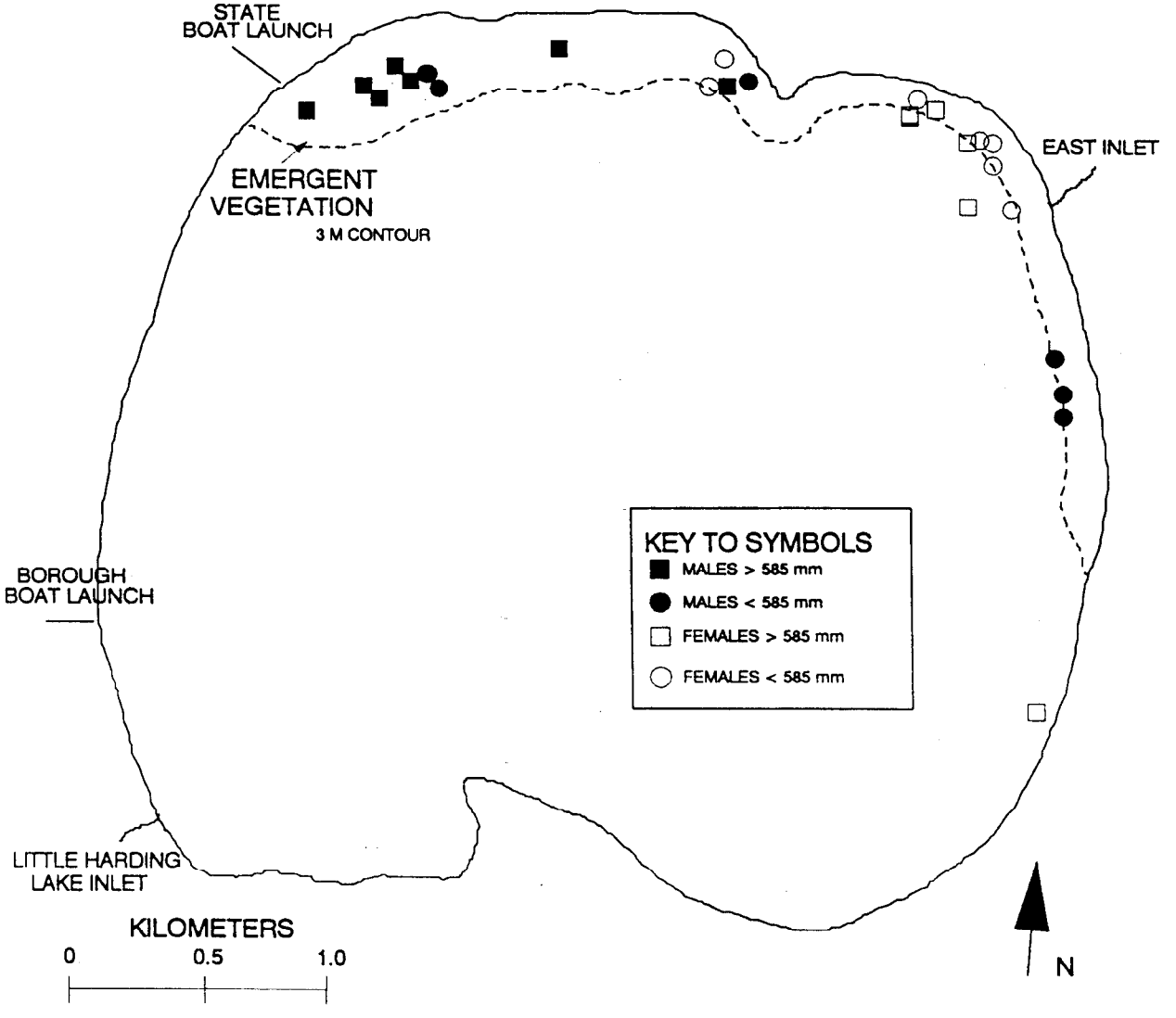
Appendix A10. Locations of radio-tagged northern pike on 17 June 1992 in Harding Lake.



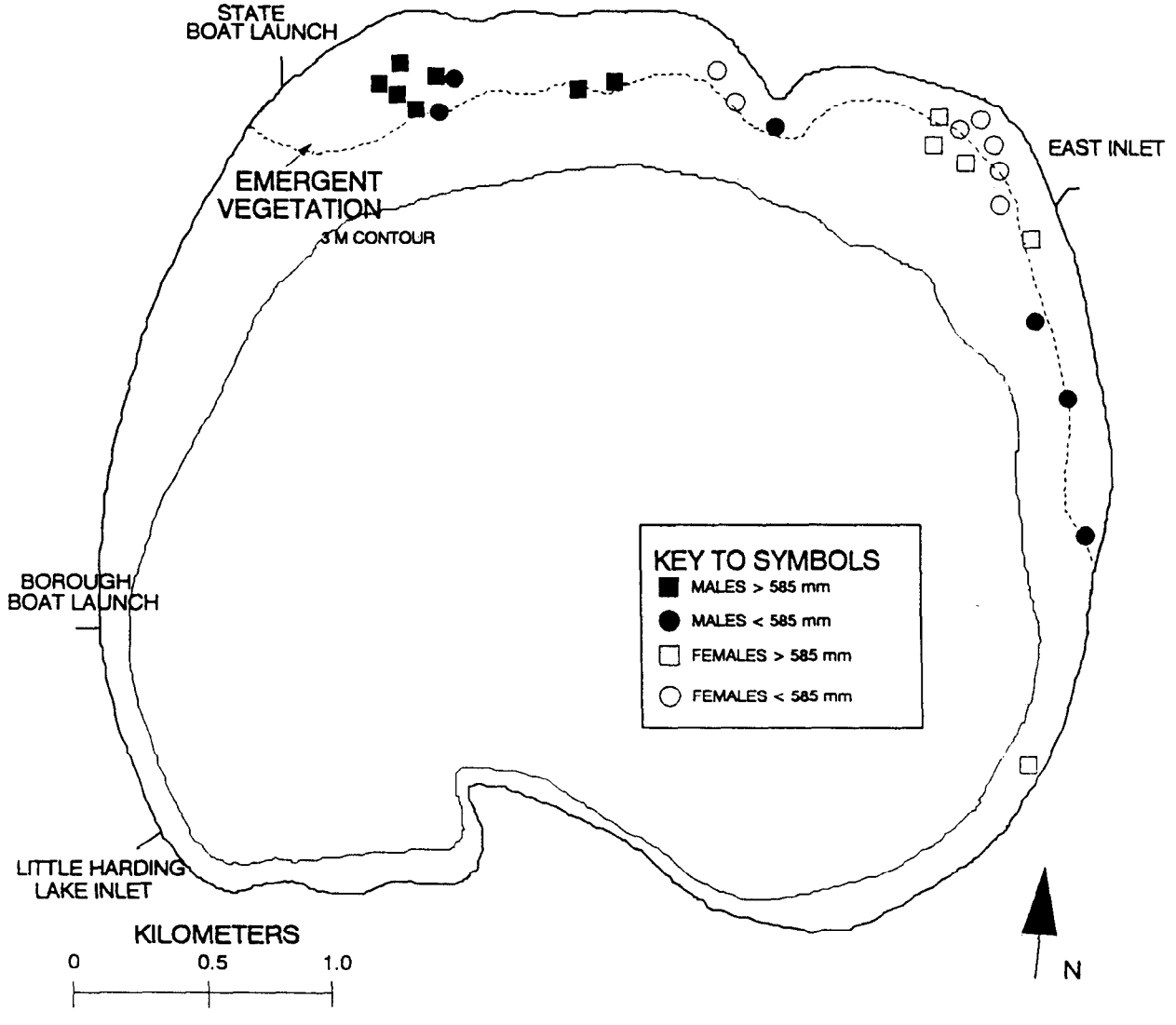
Appendix A11. Locations of radio-tagged northern pike on 18 June 1992 in Harding Lake.



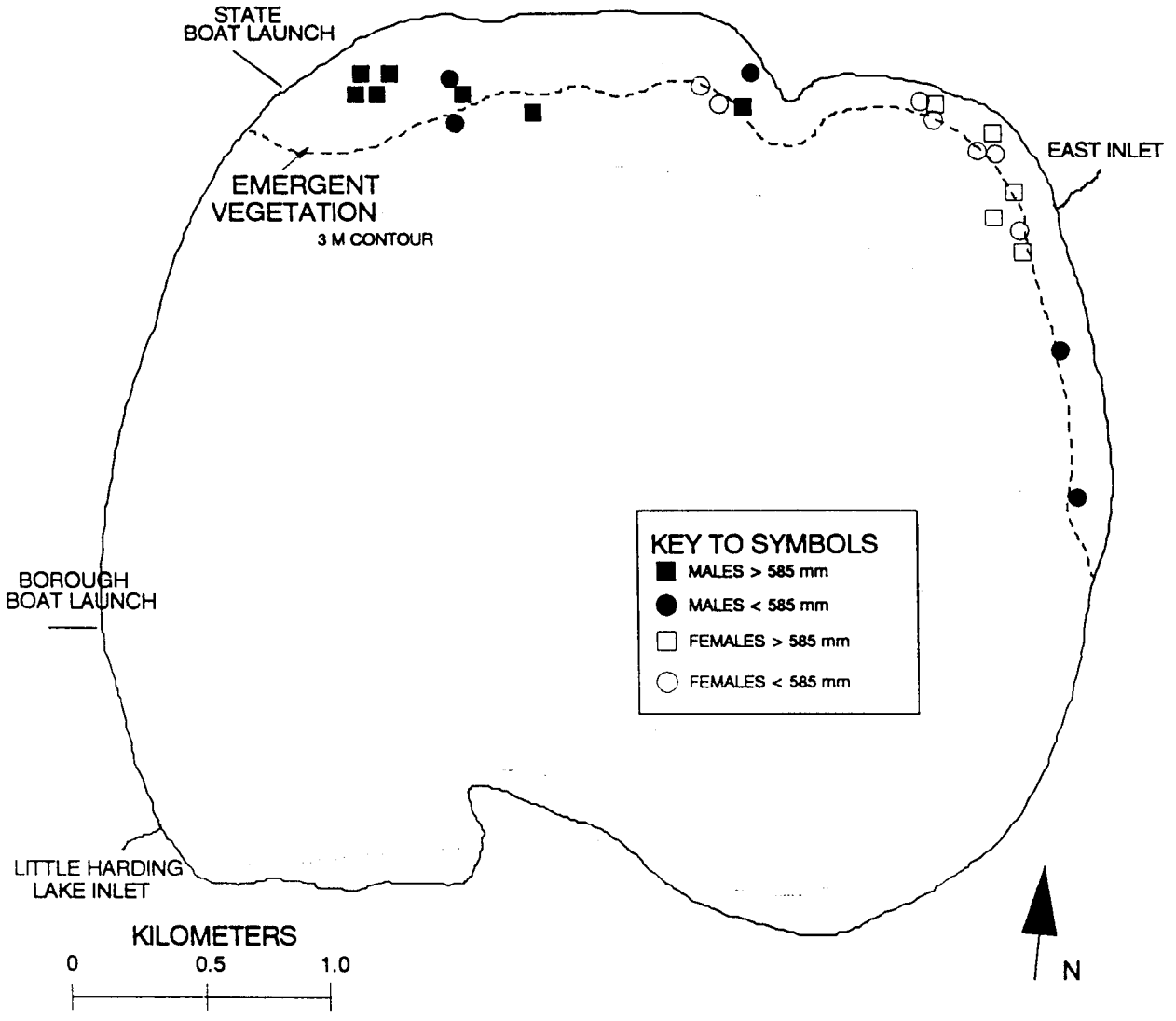
Appendix A12. Locations of radio-tagged northern pike on 19 June 1992 in Harding Lake.



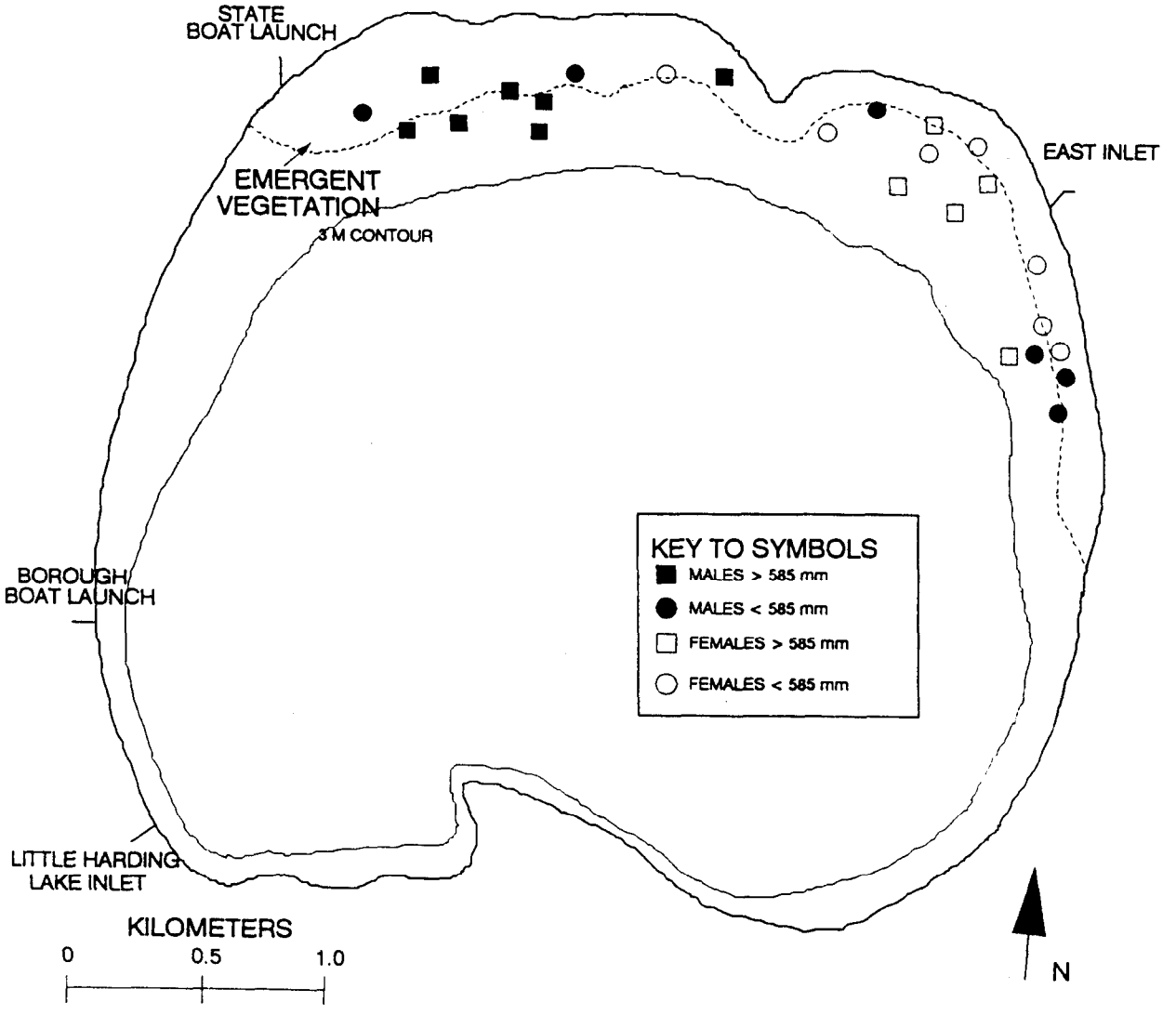
Appendix A13. Locations of radio-tagged northern pike on 20 June 1992 in Harding Lake.



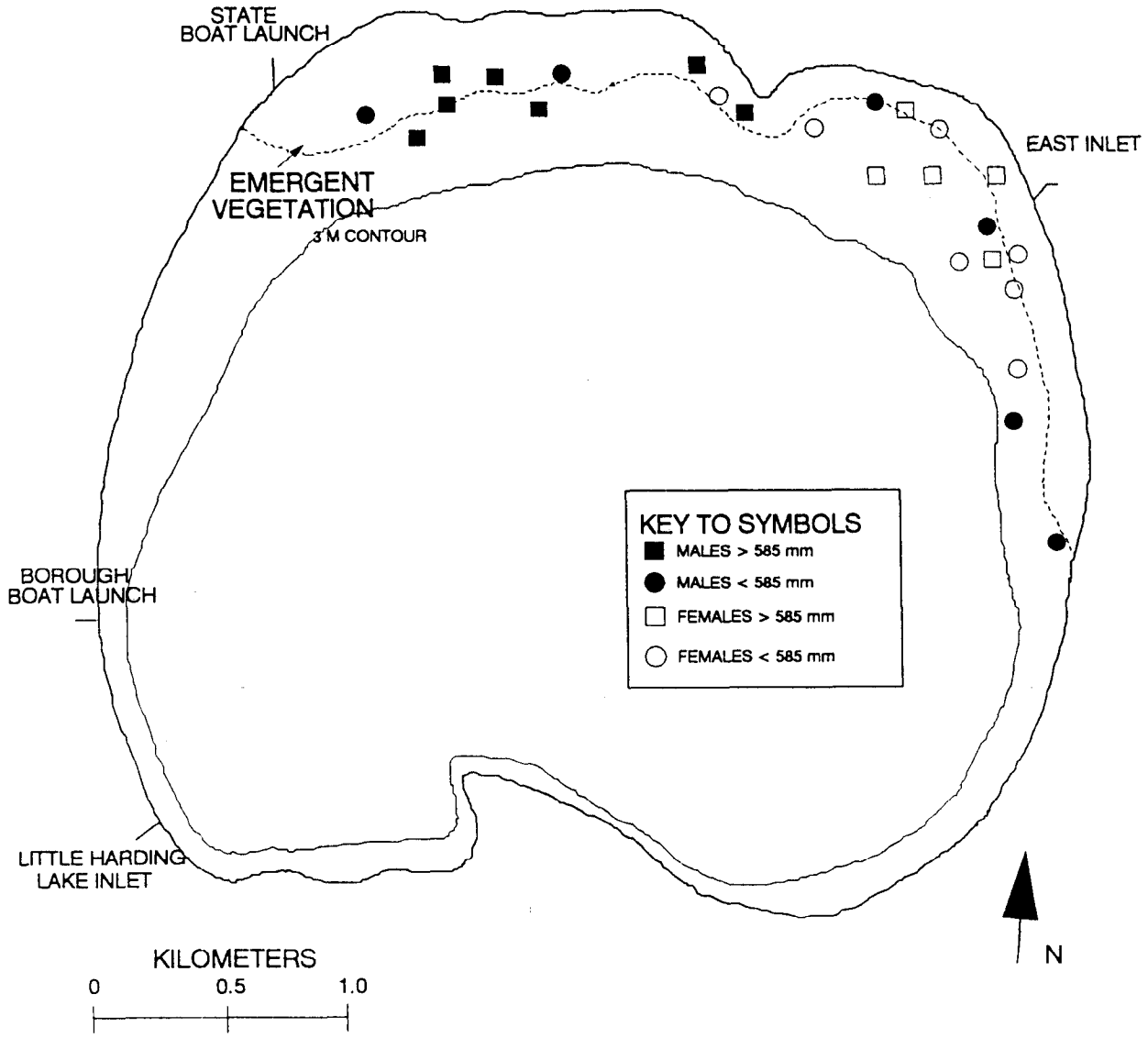
Appendix A14. Locations of radio-tagged northern pike on 22 June 1992 in Harding Lake.



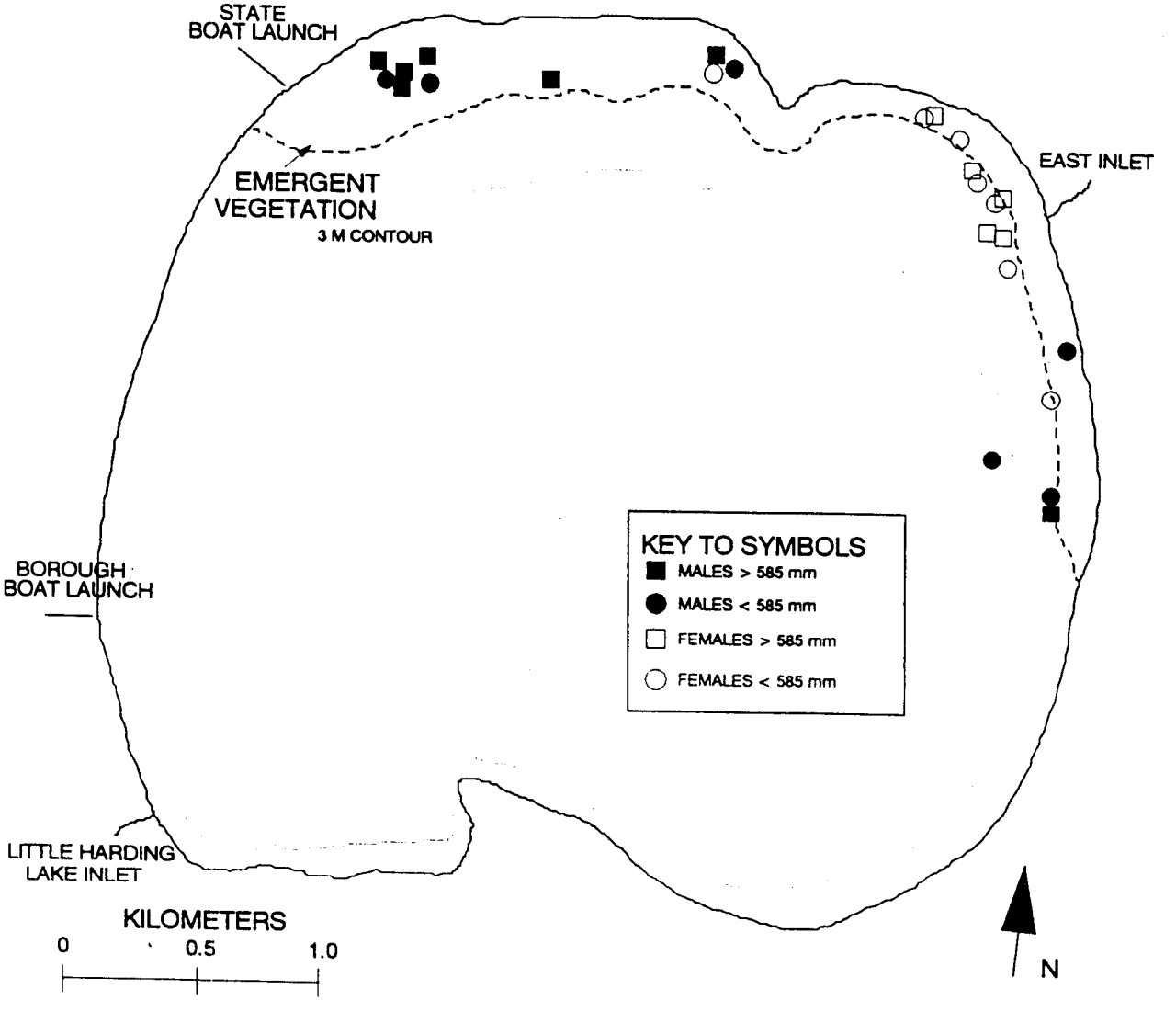
Appendix A15. Locations of radio-tagged northern pike on 23 June 1992 in Harding Lake.



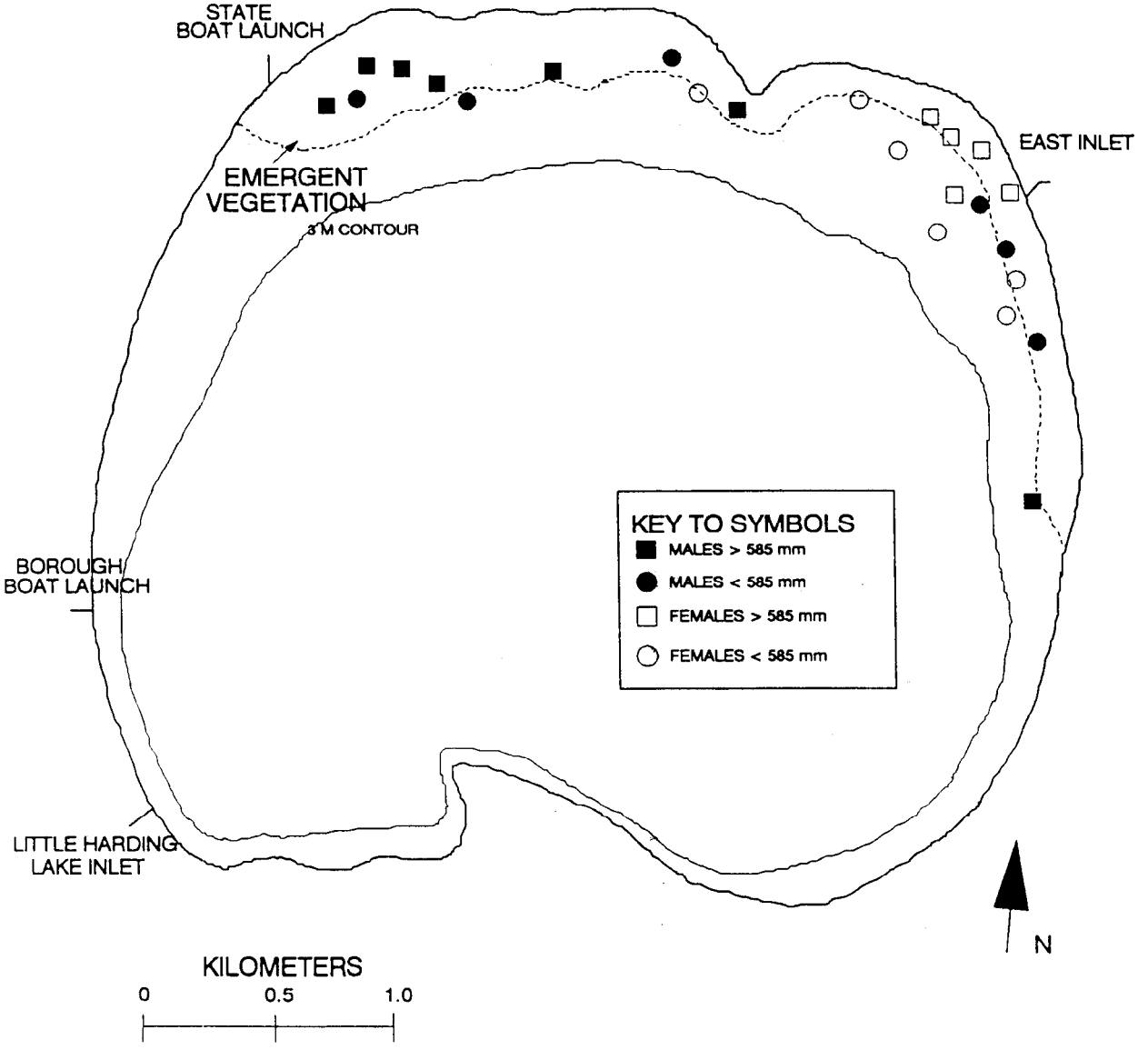
Appendix A16. Locations of radio-tagged northern pike on 24 June 1992 in Harding Lake.



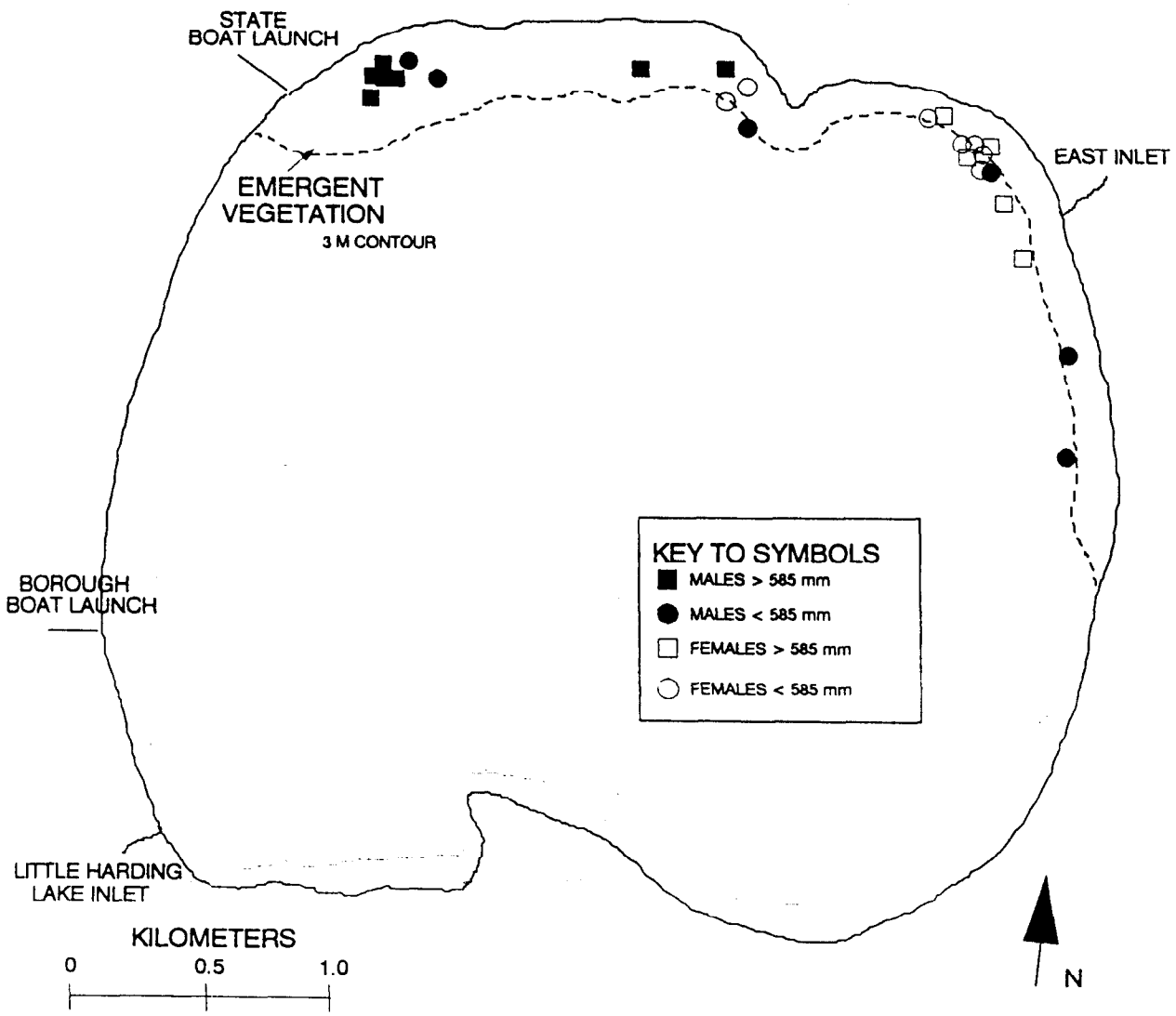
Appendix A17. Locations of radio-tagged northern pike on 25 June 1992 in Harding Lake.



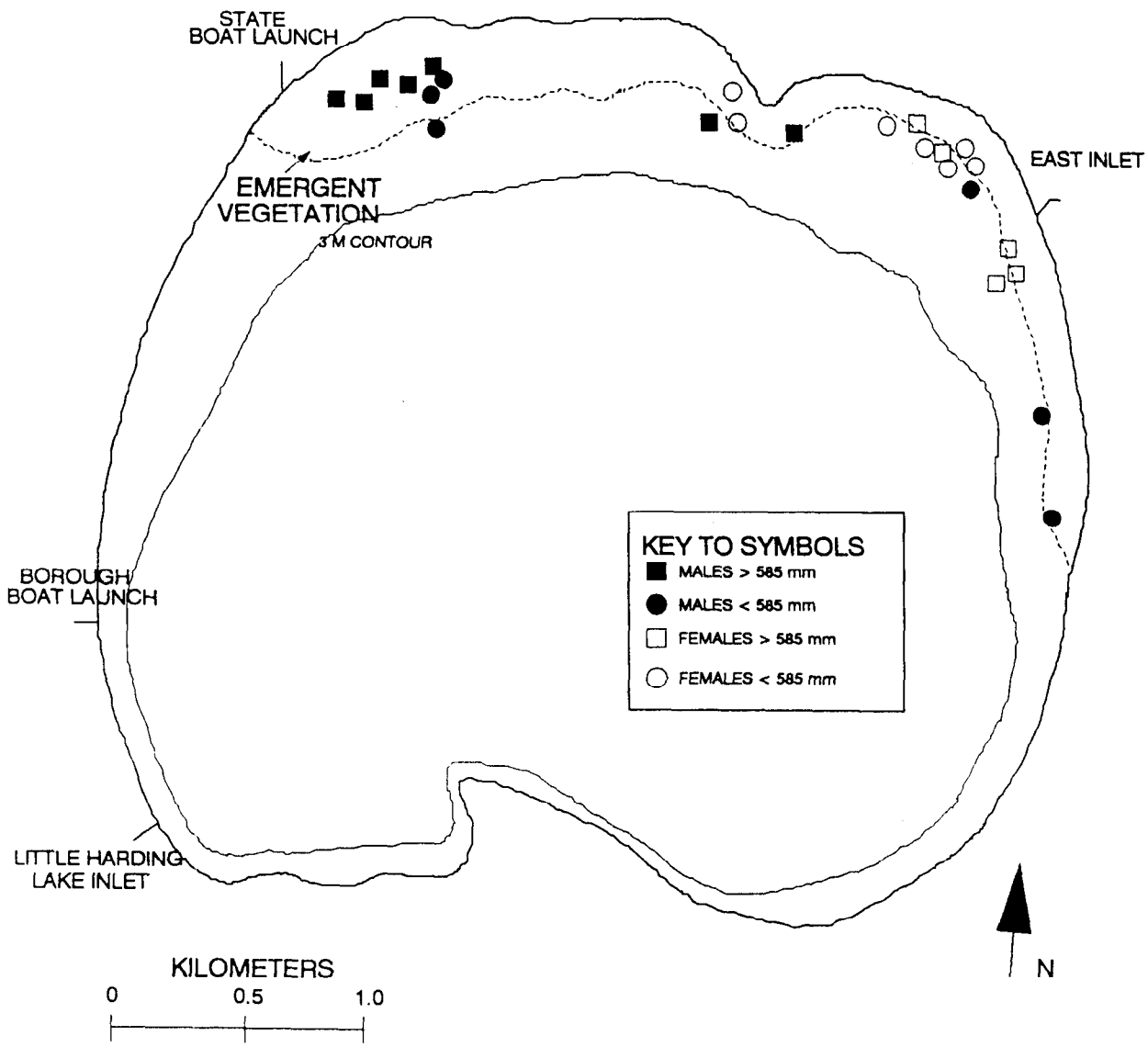
Appendix A18. Locations of radio-tagged northern pike on 26 June 1992 in Harding Lake.



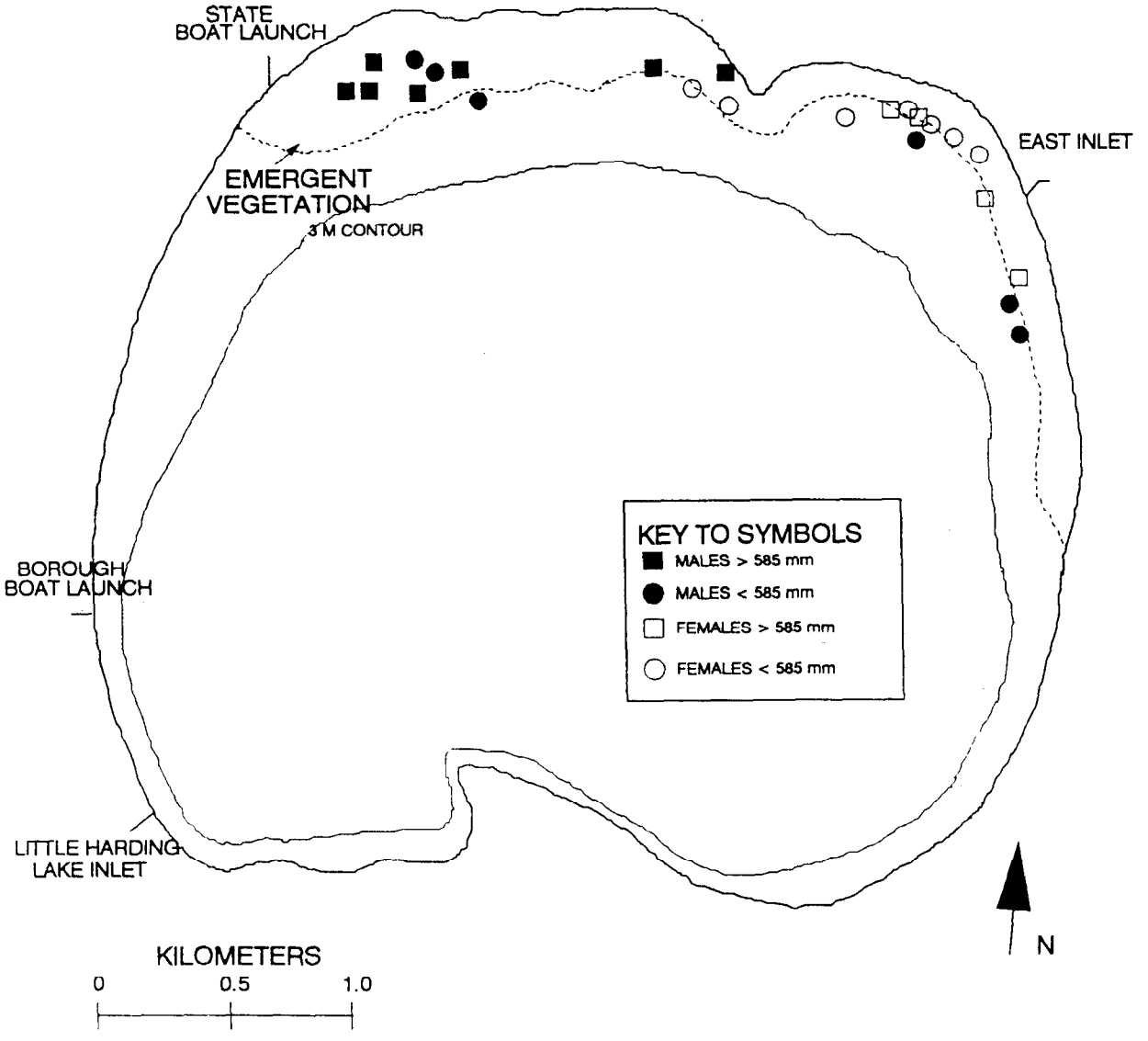
Appendix A19. Locations of radio-tagged northern pike on 27 June 1992 in Harding Lake.



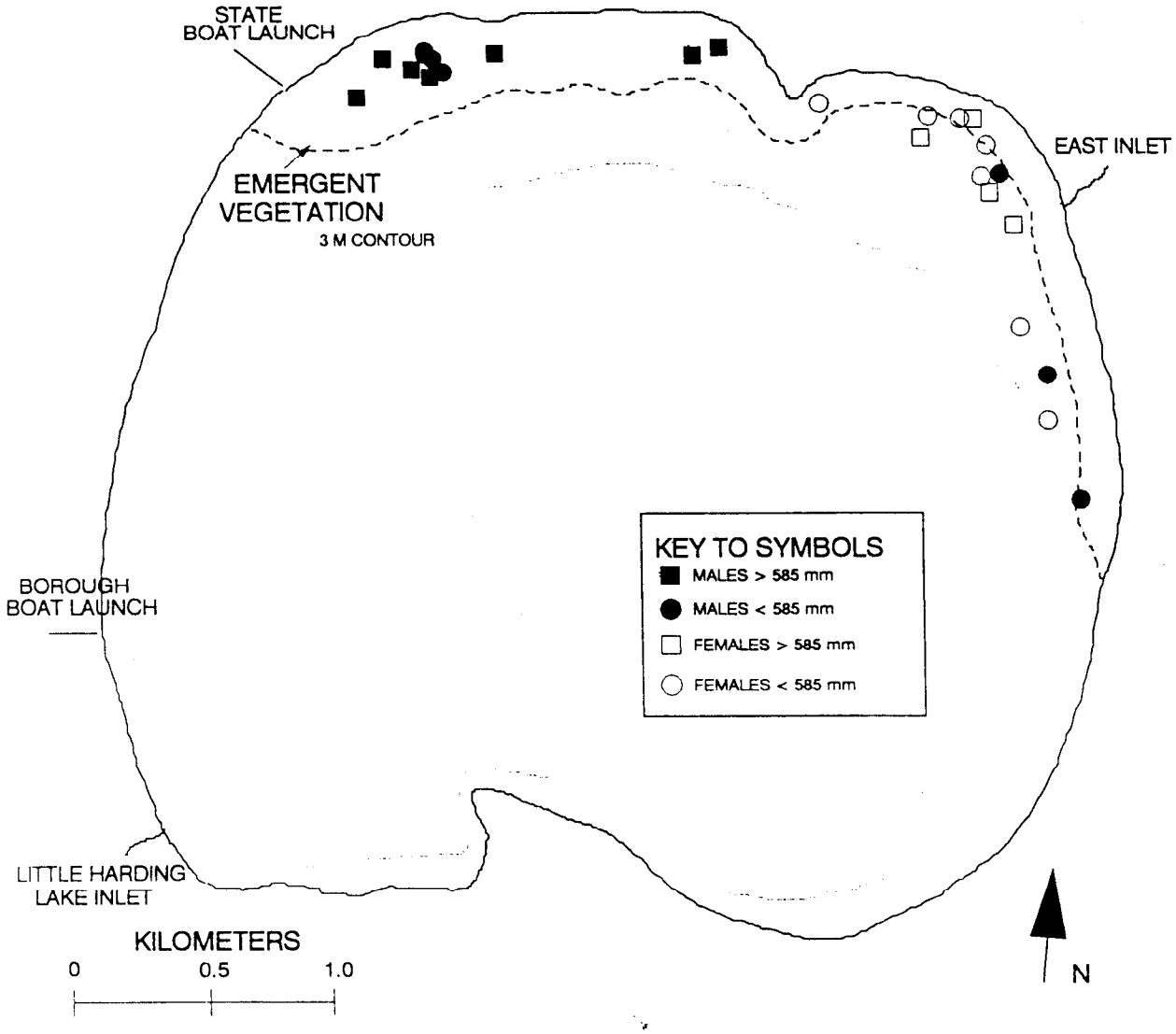
Appendix A20. Locations of radio-tagged northern pike on 29 June 1992 in Harding Lake.



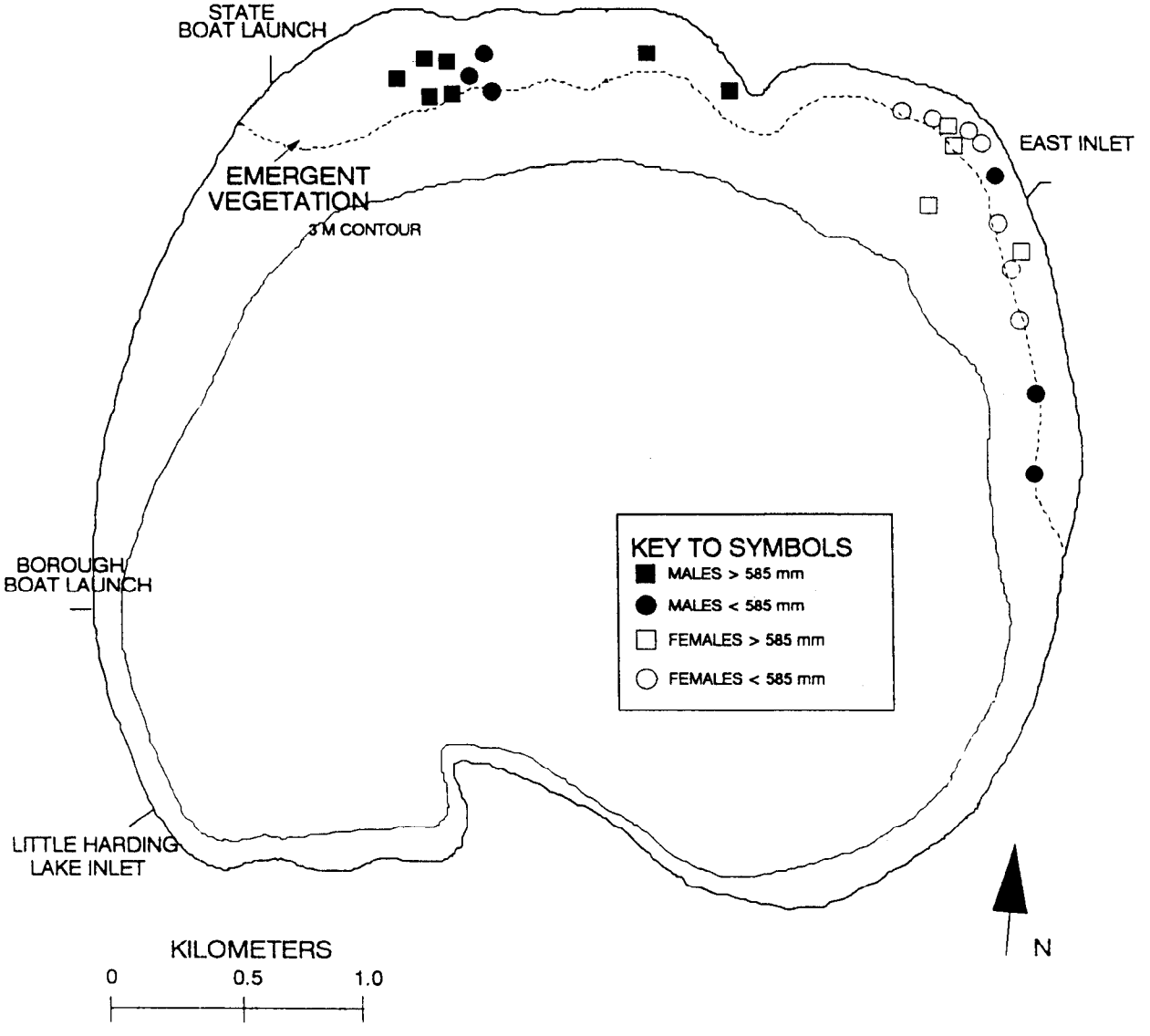
Appendix A21. Locations of radio-tagged northern pike on 30 June 1992 in Harding Lake.



Appendix A22. Locations of radio-tagged northern pike on 1 July 1992 in Harding Lake.



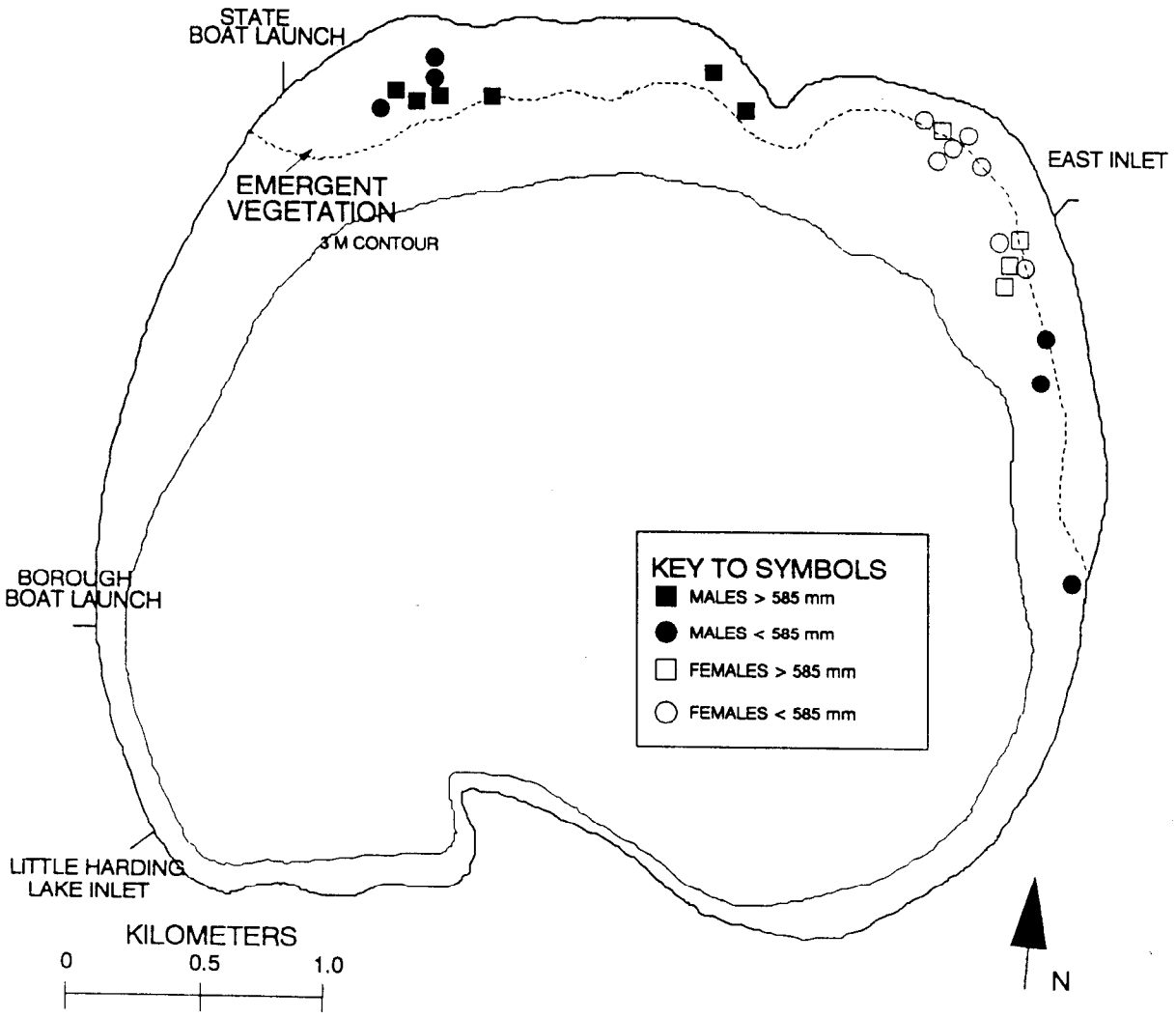
Appendix A23. Locations of radio-tagged northern pike on 2 July 1992 in Harding Lake.



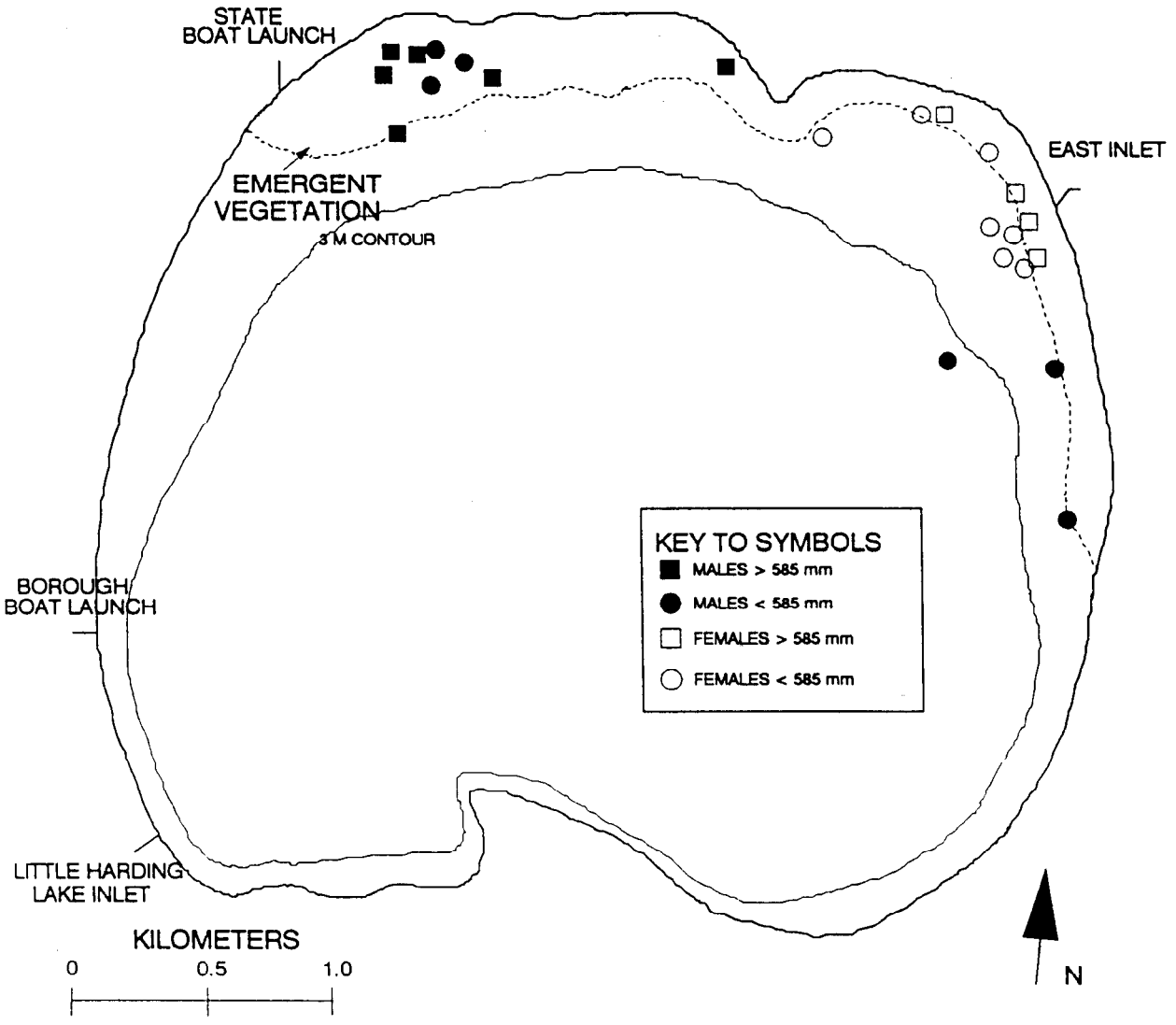
APPENDIX B

LOCATION OF FISH TRACKED WEEKLY, BIWEEKLY AND MONTHLY FROM 6 JULY TO 30 SEPTEMBER

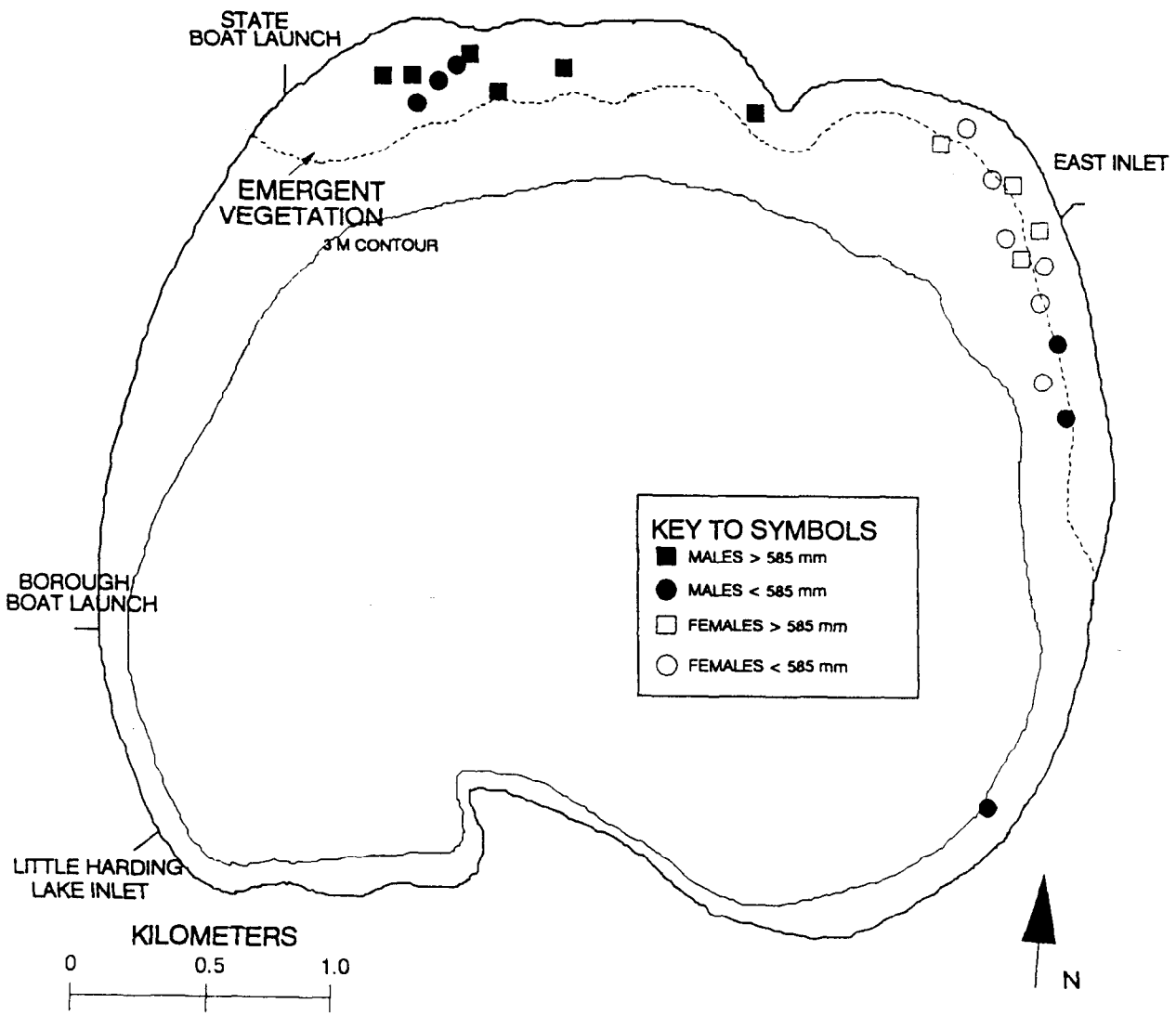
Appendix B1. Locations of radio-tagged northern pike on 6 July 1992 in Harding Lake.



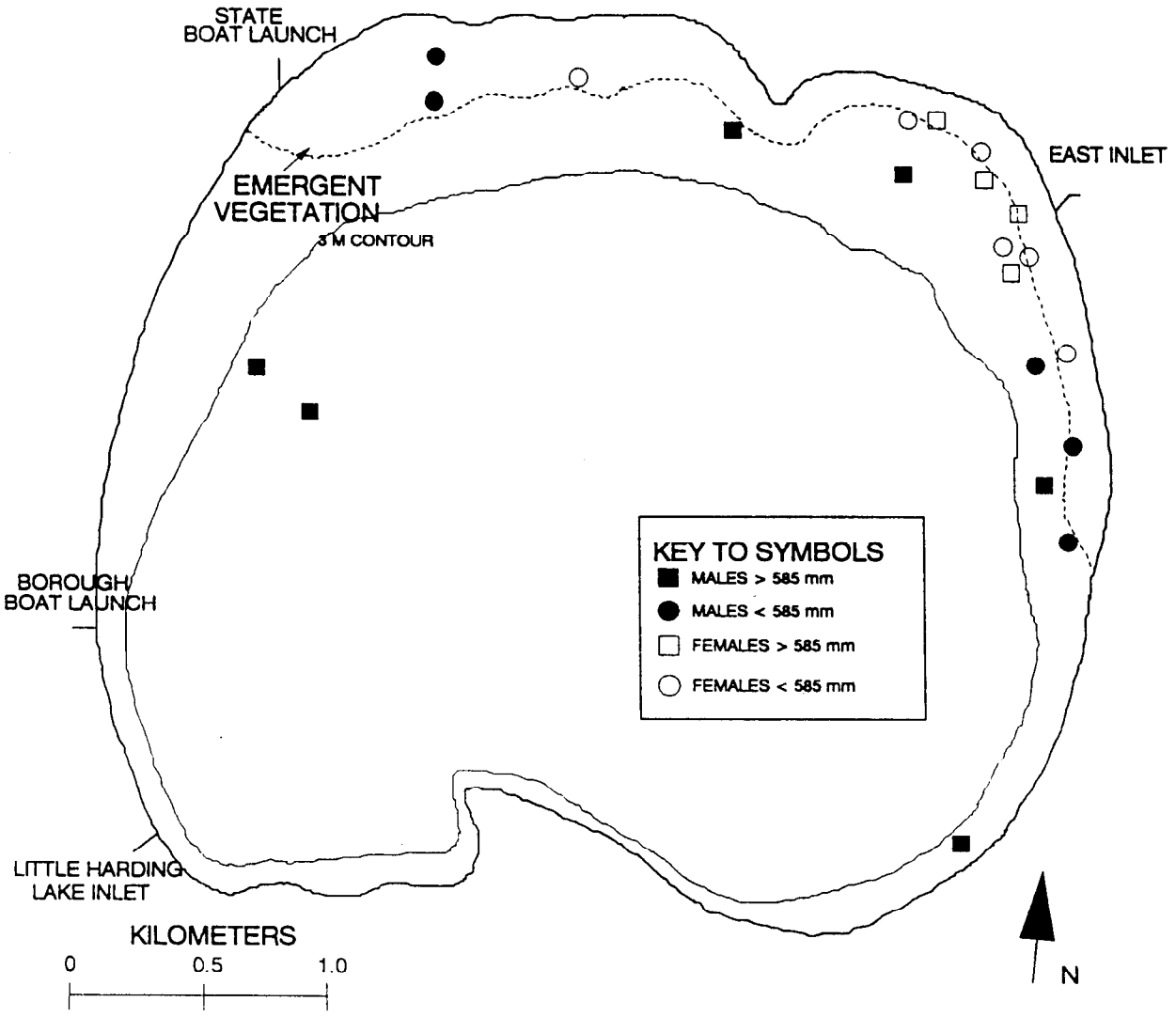
Appendix B2. Locations of radio-tagged northern pike on 13 July 1992 in Harding Lake.



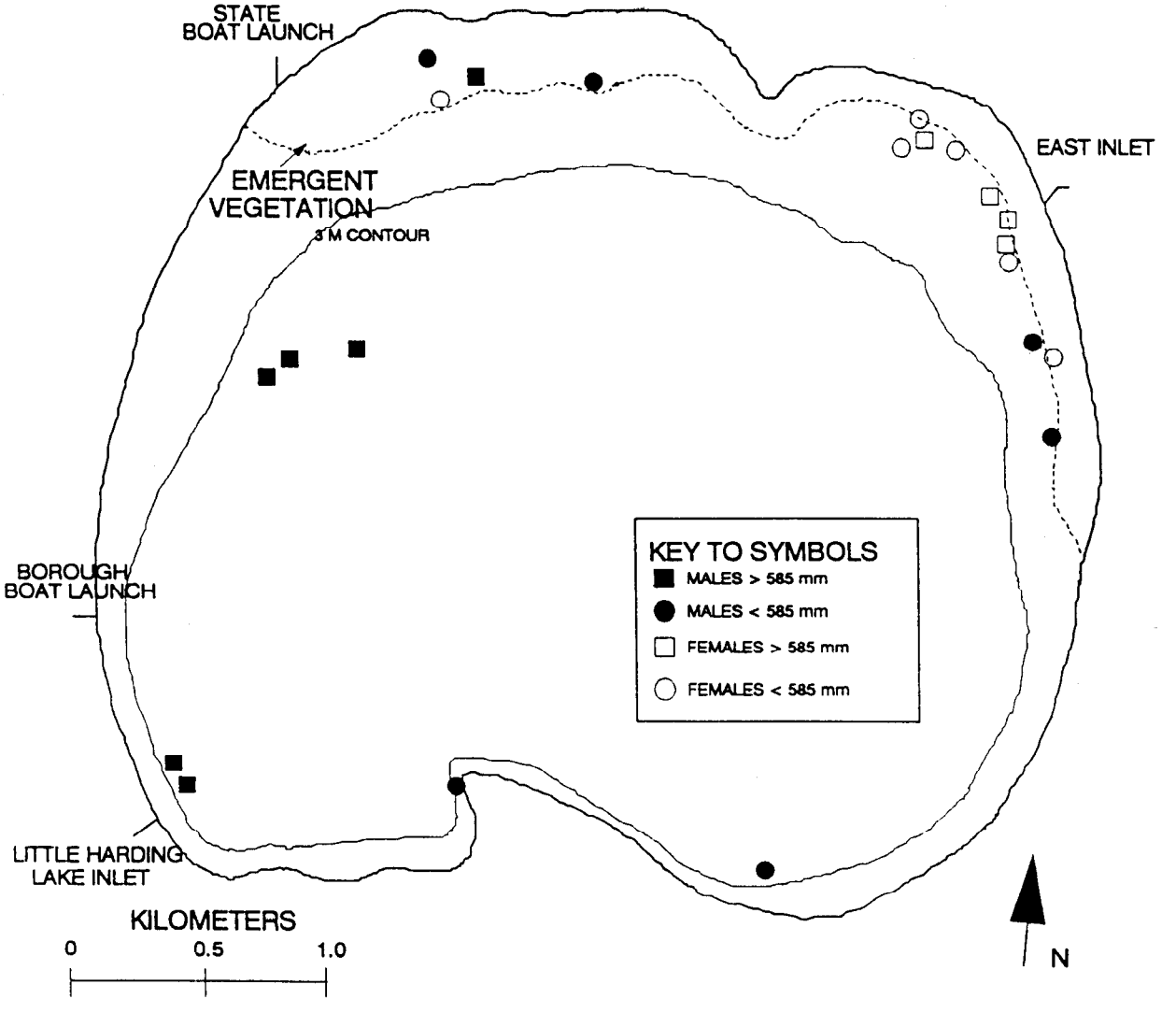
Appendix B3. Locations of radio-tagged northern pike on 20 July 1992 in Harding Lake.



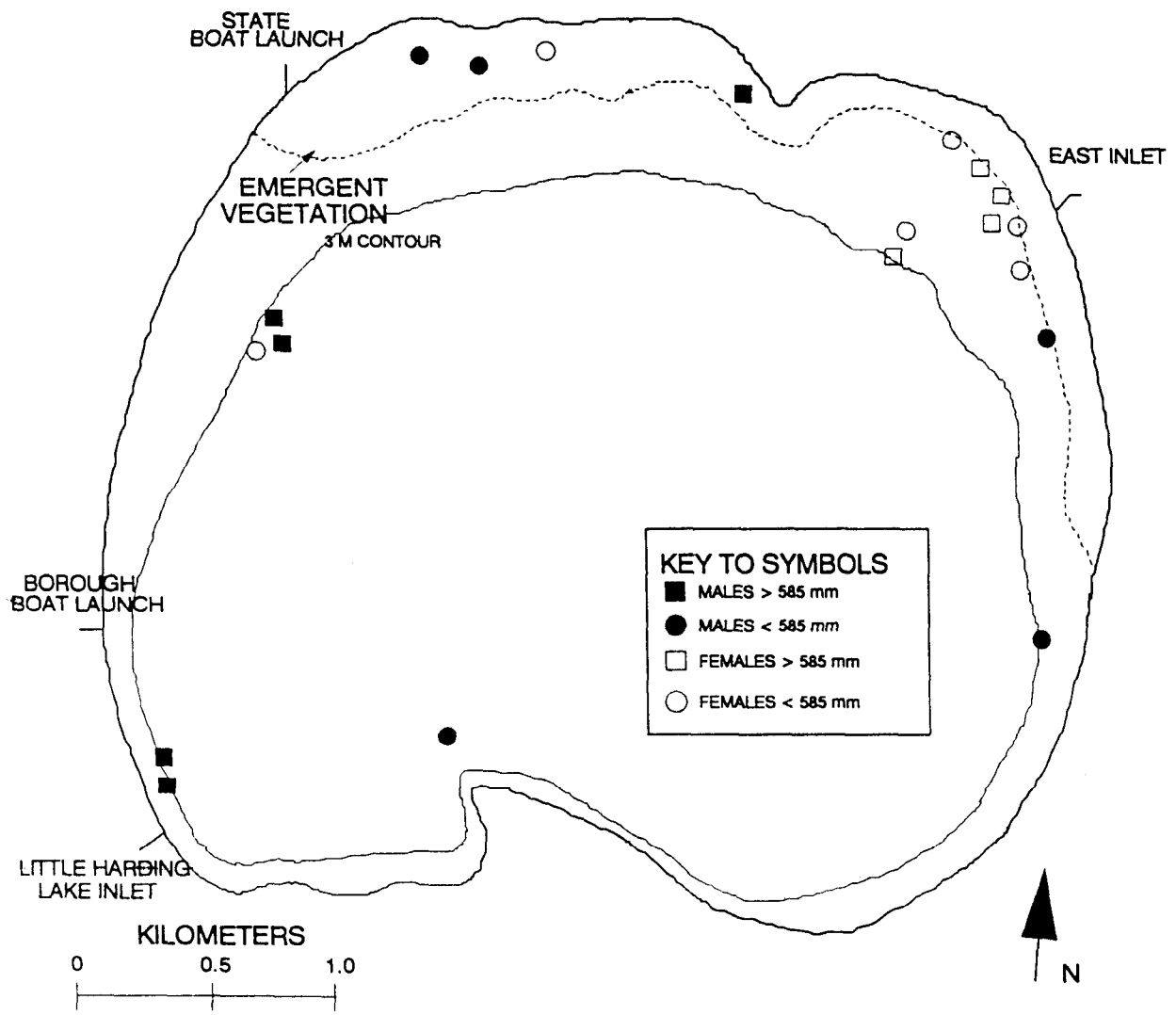
Appendix B4. Locations of radio-tagged northern pike on 27 July 1992 in Harding Lake.



Appendix B5. Locations of radio-tagged northern pike on 7 August 1992 in Harding Lake.



Appendix B6. Locations of radio-tagged northern pike on 8 September 1992 in Harding Lake.



Appendix B7. Locations of radio-tagged northern pike on 30 September 1992 in Harding Lake.